UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

A Comparison of Methods for Sampling Adult Mosquito Populations with Observations on the Biology of the Adult Females in Central Alberta, Canada.

by

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A Thesis

Submitted to the Faculty of Graduate Studies in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy.

Department of Entomology

Edmonton, Alberta

April 1968

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A comparison of sampling methods for adult mosquito populations with observations on the biology of the adult females in central Alberta, Canada" submitted by Peter Graham in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ACKNOWLEDGEMENTS

I wish to offer my sincere thanks to my supervisor Dr. B. Hocking for the time he has spent, the great amount of help and encouragement he has given me during the course of this study, and for the great help in designing and in constructing the animal bait traps. My thanks also go to Dr. W.G. Evans, Dr. G.E. Ball, and Dr. D. Boag, who have all read the manuscript in various stages of preparation and offered many valuable criticisms and suggestions during the course of the study. I wish to express my appreciation to Mr. J. Scott, Dr. M. Tawfik, and Mr. C.P. Petrone for much assistance with the figures and to Mr. Norman Wood for much help in the field in 1966 and in constructing the animal bait traps. I wish to thank Dr. W.O. Haufe and Mr. J.A. Shemanchuk of the Canada Department of Agriculture for their help and for the loan of the visual attraction trap and the base of the Rotary trap. I wish to thank Mr. W. Proctor for his great help in mechanical matters especially in repairing the generator at the field station.

I wish to express my thanks to the Parks and Recreation Department, City of Edmonton for the provision of a grant to carry out this study and for the loan of the light and Malaise traps and especially to Messers. C. Adderly, G. Dilt and J. Grant of that department for the valuable assistance they gave me. I wish to express my thanks to the University of Alberta who provided me with a Dissertation fellowship which provided financial aid for the final stage of this study. Finally, I should like to express my thanks to my fellow graduate students in the Department of Entomology especially Messers. R. Freitag, D. Whitehead, A. Nimmo and T. Pearson for the many discussions we had during the course of this study.

Frontispiece   Aedes fitchii (Felt & Young)

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1. INTRODUCTION AND METHODS

1.0 Introduction

In recent years a vast literature on sampling methods for mosquito populations has accumulated. This deals mainly with size and species composition of the catches; no critical comparisons involving the physiological state of the samples are available.

In any study of trapping methods for insects it must be realized that the catch depends on three sets of factors: those in the trap, those in the environment and those in the insect. The catch depends on the population density of the insect, its "availability" and its activity. Corbet (1961 a) considered that light traps in Uganda sampled only those mosquitoes engaged in non specific activities and did not catch those engaged in feeding, swarming, or oviposition. Biddlingmayer (1967) has published a study of the effects of environment and species composition on different trap types but has not considered the effects of the physiological state of the mosquito.

Apart from Corbet (l.c.) I know of only one study relating the physiological state of an insect of medical importance to survey methods, the work of Bursell (1961). Barr (1958) mentions that the age and physiological state of mosquitoes affects the captures in light traps, but the citation he gives for this, Nielson and Nielson (1953), is incorrect, as this paper makes no mention of factors affecting light trap captures. Russian workers have paid considerable attention to the physiological age of mosquitoes, have elucidated many factors in the biology of the insects and have provided methods for determining age (Detinova 1959, 1962) but have not related age to sampling

procedure. I have attempted to fill part of this need in relation to woodland mosquitoes in central Alberta.

1.1 The Study Area

The study area is on the west shore of George Lake, 53°57'N and 114°06'W, about 40 miles northwest of Edmonton, Alberta. The area lies at the southern margin of the boreal mixed forest sub zone. Soper (1965) and Strickland (1951) give maps and brief descriptions of the major ecological zones in Alberta. All traps were within 300 yards of the campsite, more or less in the centre of a square mile field site operated by the Department of Entomology, University of Alberta, (fig. 1).

Away from the lake shore the vegetation of the field site consists of almost untouched mature poplar forest, with small areas of spruce on the northern and western boundaries. Prior to 1930 some trees were removed by neighboring farmers, but otherwise the forest has not been disturbed. The vegetation resembles that described by Bird (1961) and Shelford (1963) for the woodland part of aspen parkland. The principal trees are Populus tremuloides Michx. and P.balsamifera L.. Other trees are Picea glauca (Moench.), Betula papyrifera Marsh., Alnus tenuifolia Nutt. and Salix species. Larix laricina Koch. is common in neighboring wetlands but rare on the field site. The understory is more diverse, consisting of a large number of shrub and herb species: Amelanchier alnifolia Nutt., Viburnum edule (Michx.), Rosa acicularis Lindl., Cornus stolonifera Michx. and Ribes lacustre (Pers.) are common shrubs. Cornus canadensis L., Solidago species, Epilobium angustifolium L., and Aster species are common herbs.

Ledum groenlandicum Oeder. forms more or less oval bogs in a few places, usually on clumps of sphagnum moss. On the northern boundary there is an area of sedge (Carex species) meadow which contains a number of permanent water holes. A stream flows out of the lake just south of the campsite and is blocked by several beaver dams. There is a fringe of Carex bordering the lake and a floating mat of Typha species round the lake edge.

About half of the surrounding country is cleared for cultivation and grazing, mainly on the east, south and northwest, resulting in a patchwork of woodland, pasture and cultivation which allows a rich mosquito fauna.

In the winter of 1964-1965 above normal snow falls were recorded and melt water remained well into summer. Also nearly 6" of rain fell in the last two weeks of June. Thus the majority of spring larvae were able to complete their development and second broods of many species developed. In the winter of 1965-1966, below normal snow falls occurred and most melt water had dried up by late spring, so many larvae did not complete development. Heavy rains did not fall till late July and August and the resulting pools soon dried up so second broods were not prominent. Heavy snow fell in the winter of 1966-1967, but did not melt till the end of April. In 1966, snow had almost disappeared by 21 April, but in 1967 it was still deep on this date. Breakup of the ice on the lake had occurred on 21 April 1966 but did not take place till the end of the first week in May, 1967. According to Mr. E. Donald, a neighboring farmer, the 1967 spring was ten days to two

weeks behind the long term average at George Lake.

An example of the difference in mosquito populations in the 1965 and 1966 seasons is given by the captures in a light trap operated at the Victoria Golf Course in the City of Edmonton. In 1965 this trap was run from the 9 July to 30 August and caught 2826 mosquitoes, an average of 75 per night. In 1966 the same trap was run from early May to the end of August and caught six mosquitoes. Control measures in the urban area were the same in both years. In the spring of 1967 traps at George Lake caught approximately four times as many mosquitoes as in the spring of 1966, though I had the impression that the mosquito nuisance in the field site was worse in 1966.

1.2 Methods

1.2.1 Identification and Key to the Adult Female Mosquitoes of Central Alberta

1.2.1.1 Literature Used: Barr (1958), Carpenter and LaCasse (1955), Happold (1965b), Rempel (1953), Steward and McWade (1961) and Vockeroth (1954b) were the principal sources used. In addition Beckel (1954) proved useful for a few badly rubbed specimens, but covers only a few central Albertan species.

None of the keys proved to be entirely satisfactory for the identification of the adult female mosquitoes taken at George Lake. I constructed a key based on the above works which appears to cover central Alberta mosquito populations more satisfactorily. This has been expanded to cover all mosquito species recorded to date from Edmonton, George Lake and Flatbush. It covers most of the species

likely to be found in the parkland and boreal forest regions of the province. I hope this key will prove useful until such time as a complete taxonomic study of Alberta mosquitoes is carried out.

1.2.1.2. Keys to the adult female mosquitoes of central Alberta.

1.2.1.2.1. Key to Genera -

1.		Palps almost as long as proboscis; scutellum rounded	*Anopheles earlei*
		Palps short, less than 1/3 length of proboscis; scutellum trilobed	2
2.	(1)	Spiracular bristles present	*Culiseta*
		Spiracular bristles absent	3
3.	(2)	Post spiracular bristles present; tip of abdomen pointed	*Aedes*
		Post spiracular bristles absent; tip of abdomen rounded	4
4.	(3)	Wings with many pale scales, wing scales broad	*Mansonia perturbans*
		Wing scales all dark and narrow	*Culex*

1.2.1.2.2. Key to *Culex* species (from Rempel, 1953)

1.		Tarsal segments ringed with white	*tarsalis*
		Tarsal segments not ringed with white	2
2.	(1)	White bands on apices of abdominal tergites	*territans*
		White bands on bases of abdominal tergites	*restuans*

1.3.1.2.3. Key to *Culiseta* species

1.		Hind tarsal segments ringed with white	2

		Hind tarsal segments not ringed with white	5
2.	(1)	Wing scales forming conspicuous spots	3
		Wings without conspicuous spots	4
3.	(2)	Tarsal white rings broad; very large species	*alaskaensis*
		Tarsal white rings narrow	*incidens*
4.	(2)	Abdominal pale bands on bases of tergites only, white in color	*morsitans*
		Abdominal pale bands on both apices and bases of tergites, usually pale yellow brown in color	*minnesotae*
5.	(1)	Costa of wing with mixed pale and dark scales	*inornata*
		Costa with dark scales only	*impatiens*

1.2.1.2.4. Key to *Aedes* species (based on Vockeroth 1954b)

1.		Hind tarsal segments ringed with white	2
		Hind tarsal segments not ringed with white	11
2.	(1)	Tarsal white rings on both apices and bases of tarsal segments	3
		Tarsal white rings on bases of tarsal segments only	5
3.	(2)	Wings with both dark and light scales on most veins	4
		Wing scales entirely dark	*canadensis*
4.	(3)	Dark and light scales equally distributed on veins	*campestris*
		Third vein (R4+5) with more dark scales than 2nd (R2+3) or 4th(M)	*dorsalis*
5.	(2)	Tarsal white rings very narrow, 1/4 or less than length of segment	*vexans*
		Tarsal white rings broader, at least 1/3 of length of segment	6

6.	(5)	Large yellow species; abdominal tergites almost completely yellow scaled; tarsal claw as in fig. 2b 4.	<u>flavescens</u>
		Not as above, abdominal tergites with abundant dark scales	7
7.	(6)	Tarsal claw large, main claw almost parallel to accessory tooth and slightly sinuate, fig. 2b 1.	<u>excrucians</u>
		Tarsal claw smaller, not sharply bent beyond tooth	8
8.	(7)	Mesonotum with some contrasting markings; tarsal claw with long accessory tooth, fig. 2b 2.	9
		Mesonotum almost uniform yellow brown; tarsal claw with short accessory tooth, fig. 2b 3.	<u>riparius</u>
9.	(8)	Palps and torus with some white scales; lower mesepimeral bristle 1. 2 or absent	<u>fitchii</u>*
		Palps and torus usually without white scales; lower mesepimeral bristles 3 or more	10
10.	(9)	Palps lacking hairs on basal half of apical segment at inner edge	<u>increpitus</u>*
		Palps with hairs on basal half of apical segment at inner ventral edge	<u>stimulans</u>*
11.	(1)	Fore coxa with a patch of brown scales on anterior surface; small species	<u>cinereus</u>
		Fore coxa with patch of white scales on anterior surface	12
12.	(11)	Wing scales distinctly bicoloured	13
		Wing scales all dark or with pale scales restricted to base of costa	14
13.	(12)	Wings with pale and dark scales intermixed, dark predominating; lower mesepimeral bristles usually present	<u>niphadopsis</u>
		Wing veins alternating black and white scaled; lower mesepimeral bristles absent	<u>spenceri</u>

14.	(13)	Post-coxal scale patch present, fig. 2a.	15
		Post-coxal scale patch absent	21
15.	(14)	Hairy species, postpronotum with setae scattered over posterior half	_impiger_
		Less hairy species, postpronotal setae restricted to a single or irregular double row along posterior margin	16
16.	(15)	Sides of mesonotum silvery grey; base of costa with numerous white scales in a conspicuous patch	17
		Sides of mesonotum yellow or dark; base of costa with only a few or no white scales	19
17.	(16)	White scales on costa covering basal 1/7	_cataphylla_
		White scales on costa restricted to extreme base	18
18.	(17)	Sternopleuron with scales extending to anterior angle; mesonotum with numerous white scales giving a "frosted" appearance, medium stripe indistinct	_trichurus_
		Sternopleuron with scales extending half way to anterior angle; mesonotum with a distinct median brown stripe	_implicatus_
19.	(16)	Bristles of scutellum and mesonotum black; postmetasternal membrane with 15 or more scales	_pionips_
		Bristles of scutellum and mesonotum yellow or bronze; postmetasternal membrane bare or with less than 12 scales	20
20.	(19)	Base of costa with a distinct patch of white scales	_hexodontus_
		Base of costa with no or a few scattered white scales at most	_punctor_
21.	(14)	Hypostigial scale patch present, fig. 2a	_pullatus_
		Hypostigial scale patch absent	22

22. (21) Scales on sternopleuron reaching to anterior angle; mesepimeron scaled to near lower margin; mesonotum with contrasting dark lines 23

Scales of sternopleuron reaching half way to anterior angle; lower 1/3 of mesepimeron bare; mesonotum usually uniform yellow brown ..... <u>intrudens</u>

23. (22) Bristles of scutellum and mesonotum bright yellow; abdominal white bands indistinct or absent ..... <u>diantaeus</u>

Bristles of scutellum and mesonotum black or bronze; abdominal white bands distinct 24

24. (23) Lower mesepimeral bristles present ..... <u>communis</u>

Lower mesepimeral bristles absent ..... <u>sticticus</u>

* Adult females of these species cannot be distinguished with any certainty.

<u>1.2.1.3. Notes on identifications of Adult Females</u> - The characters given in the key should enable most specimens of adult female mosquitoes from central Alberta to be identified, provided they are not badly rubbed, but some qualifications and explanations are necessary.

Central Albertan species of <u>Anopheles</u>, <u>Culex</u>, and <u>Mansonia</u> present no problems and even badly rubbed specimens of these genera can usually be determined. The only confusion likely in <u>Culiseta</u> is that rubbed specimens of <u>C.minnesotae</u> Barr may be mistaken for <u>C.morsitans</u> (Theobald). Here a close examination will usually reveal a few pale scales on the apices of the tergites.

The genus <u>Aedes</u> presents most of the identification problems and all specimens unidentified in this study were in this genus. <u>Aedes</u> <u>cinereus</u> Meigen is best distinguished by the brown patch of scales

of *A.fitchii* only have been found at George Lake.

Black legged *Ochlerotatus* are also a difficult group. *A.punctor* (Kirby) and *A.hexodontus* Dyar occur in two forms; "tundra" type with uniform yellow brown mesonota and "punctor" type which have contrasting lines on their mesonota. Wada (*l.c.*) considered the best way to distinguish these two species was the presence of a white spot on the base of the costa of *A.hexodontus*, but Jenkins and Knight (1950) state that *A.punctor* "tundra" type may also have a few white scales on the costal base. The criterion I used was - a conspicuous white spot on the base of the costa-- *A.hexodontus*; none or only a few scattered white scales on the base of the costa-- *A.punctor*.

Vockeroth (1953, 1954b) has discussed the separation of *A.pionips* Dyar from *A.communis* (De Geer). The presence of a postcoxal scale patch in *A.pionips* appears to be the best character. I could find no completely satisfactory way of distinguishing *A.pionips* from *A.punctor* or *A.hexodontus*. The black mesonotal bristles are usually adequate but some specimens of *A.punctor* and *A.hexodontus* have dark bronze bristles. These may be separated with difficulty on the characters given by Beckel (1954).

A.intrudens, *A.communis*, and *A.sticticus* (Meigen) present some problems of differentiation. *A.intrudens* is the only species without a postcoxal scale patch which normally has no contrasting lines on the mesonotum, but a few individuals have indistinct lines on the mesonotum and closely resemble *A.communis*, and a few of these may lack lower mesepimeral bristles and resemble *A.sticticus*. The scale patch

on the sternopleuron which only reaches half way to the interior angle in A.intrudens will distinguish these. The presence of lower mesepimeral bristles will distinguish A.communis from A.sticticus and the bright yellow mesonotal bristles and incomplete abdominal bands distinguish A.diantaeus Howard, Dyar and Knab from other species without a postcoxal scale patch.

1.2.2. Sampling

Nine methods of sampling adult mosquitoes - Malaise traps, New Jersey light traps, a visual attraction trap, a rotary sweep net, chicken bait, rat bait, human bait, carbon dioxide bait, and collections of resting mosquitoes inside a trailer - were tested in this study. The localities of these traps are shown in fig. 1. Traps used in different years were operated in the same places.

All meteorological data were obtained from a recording thermo-hygrograph in a Stevenson screen at the campsite.

1.2.2.1. Malaise traps - This type of trap was first described by Malaise (1937), but its importance in ecological studies has only recently become apparent. Many modifications have been described (Gressitt and Gressitt 1962; Townes 1962; Butler 1965). I chose the modification of Townes (l.c.) as it is operational from all four directions, though it is less portable than some of the others. Breeland and Pickard (1965) and Smith et al (1965) have recently demonstrated the value of this type in mosquito studies.

One trap was used in 1965 and two in 1966 and 1967. These had four entrances four feet high and six feet wide and the catching

nets swept the same volume of air. The nets were 12.5 inches in diameter and the trap made one complete revolution per second, thus the trap swept 1167 cu. ft. of air per minute (fig. 10). The insects caught were removed with an aspirator. Operation of this trap was also restricted by the power supply.

Rotary traps have been used by several workers (Chamberlin 1940; Chamberlin and Lawson 1945; Stage and Chamberlin 1945; Stage et al 1952; Love and Smith 1957) who assumed they have no attraction for insects and take unbiased random samples.

1.2.2.4. Visual attraction trap - A visual attraction trap of the type described by Haufe and Burgess (1960) and Haufe (1964) was used, with a net, instead of the hourly timing device described, for collecting the catch (fig. 11). Unfortunately, only one trap was available and the power supply permitted only restricted hours of operation.

The cylinder made one complete revolution every two seconds and the air flowed through the trap at 741 cu. ft./min. Complete engineering blue prints of this trap are obtainable from the Canada Department of Agriculture, Medical and Veterinary Entomology Branch, Lethbridge, Alberta.

This type of trap was originally developed for use in the north, where short summer nights make light traps inefficient. Shemanchuk (1959) and Haufe (1964) have shown that they work efficiently at lower latitudes.

1.2.2.5. Chicken bait traps - Two small traps were constructed in

1965, each held one chicken. These were not very successful.

Two large traps each capable of holding several birds were used in 1966. They were six feet long, by four feet wide, twelve inches high at the corners and twenty two inches high at the centre. One end was closed in with a roosting box 17 inches by four feet in dimension. The floor was one inch mesh wire cloth. Four egress traps protruded from the roosting box, two on each side. The rest of the sides were made of 14 x 18 inch mesh galvanized wire gauze. Ingress traps were tried but the birds sat on them and broke them. The mosquitoes entered by the wire cloth floor and were caught in the egress traps as they left. The traps did not catch many mosquitoes, possibly because the birds ate them.

The two traps were designated CBI and CBII (figs. 15 & 16). CBI was baited with white leghorns and CBII with bantams. The latter often escaped so that the number in the trap varied from two to five. These traps were only operated in 1966.

1.2.2.6. Rat baited traps - The two traps used with chickens in 1965 were modified and used with rats in 1966. Each was of a different design. They were designated RBI and RBII. RBI was a modified Magoon (1935) trap 19 inches long and 17 inches wide and 12 inches high. The animal chamber was closed in by 14 x 18 inch mesh galvanized wire gauze so that the mosquitoes could not reach the bait. The mosquitoes entered a collecting cage 19 inches long, six inches high and six inches wide by means of a no-return baffle and were removed with an aspirator. RBII was a circular trap, 15 inches in diameter with the

bait cage coming to a cone 12 inches high. This cone projected through a hole 3 inches in diameter in the top plate into a cone 3 inches high in the bottom of the collecting cage, the two forming a no-return baffle. The catching cage was a removable cylinder 9 inches high and 10 inches in diameter. Flanges 6 inches wide in RBI and 41/2 inches wide in RBII were added in 1966 to direct the mosquitoes into the trap. These traps are shown in figs. 13 ~~&~~ and. 14.

Originally three rats were used in each cage, but births often modified this. These two traps were run close to each other in the middle of the campsite. RBI was operated in June, July and August 1966 and May and June 1967, RBII was only operated in July and August of 1966.

Many designs have been suggested for animal bait traps using large animals, the so-called stable traps of Magoon 1935, Bates 1944, Roberts 1965 but relatively little attention has been given to the use of small animals as mosquito bait (Southwood 1966). These would appear to offer certain advantages because of their smaller size and the fact that they need less attention than cattle or horses.

1.2.2.7. Carbon dioxide baited traps - Several authors (Brown 1951, Bellamy and Reeves 1952, Newhouse et al. 1966 and others) have shown that carbon dioxide used alone or in conjunction with another attractant is good bait for mosquitoes. I decided to try the release of carbon dioxide from a cylinder in Malaise traps. The gas was released at from one to six litres per minute, with an average rate of 5.0

litres per minute (approximately equivalent to the amount of carbon dioxide expired by twenty men at rest). It proved difficult to control the flow accurately in the field with changing condition of temperatures and barometric pressure. The gas was released through a flowmeter and led up into the catching head by means of a plastic tube (fig. 12). On the night of 12/13 July, 1966 releasing the gas direct from the cylinder without a flowmeter was tried. Both 25 lb. and 50 lb. cylinders of carbon dioxide were tried, the former proved better as they were more portable. One 25 lb. cylinder lasted approximately 16 hours. The traps were run from 1700 hours to 0900 hours the following morning.

Carbon dioxide was used on alternate nights, the other Malaise trap being used as a control. Carbon dioxide traps were operated in July and August 1966 and May and June 1967.

1.2.2.8. Human bait - On one day in most weeks from late May to the end of August, 1966, I sat quietly with trouser legs rolled up and caught any mosquitoes which alighted in a fifteen minute period. In May these collections were made in the afternoon and after that at 1800 hours.

1.2.2.9. Collections of resting mosquitoes and miscellaneous collections - Also on one day per week in June, July and August, 1966 and from 16 May to 15 June 1967, all mosquitoes found resting in one of the trailers at the camp were collected early in the afternoon. In June 1966 this trailer was used as a kitchen and dining room, thereafter as a store. In 1966 a carton of dry ice

was kept in it and rats were kept there over weekends in a screened cage. In 1967 rats were kept in the trailer in an unscreened cage.

At various times during the summer of 1966, mosquitoes were caught with a sweep net, when biting at times other than when human bait captures were in progress and in a C.D.C. (Communicable Diseases Center) miniature light trap. These collections have been included only in total catch figures.

1.2.3. Handling and Dissection

Weekend catches of Malaise traps, human bait, and miscellaneous collections were identified and counted. All other collections were frozen and taken to the laboratory. There they were identified, counted and dissected or, if numerous, subsampled and dissected. In 1967 the very large collections in carbon dioxide traps were subsampled for dissection and subsampled again for identification. The number of specimens in each sample was estimated from these two subsamples, this estimated number was used to obtain the proportion of each species in the total carbon dioxide trap catch. The number identified varied from 100% to 20% of the total, being proportionately smaller in the larger samples. This is probably an accurate estimate of the numbers of the more numerous species but not of the rarer ones.

Specimens for dissection were first assigned to a stage of Sella (Sella 1920, Detinova 1959, 1962) and to one of five arbitrary categories of external wear. They were dissected in distilled water under X12 of a Wild M5 stereo microscope. The contents of the ventral oesophageal diverticulum and the mid gut were noted. The ovaries were

then examined under X50 for the stage of Christophers (Christophers 1911, Puri 1957, Detinova l.c., Clement 1963).

The ovaries were removed to a drop of water on a microscope slide, allowed to dry and stored till they could be examined for parity or nulliparity by Detinova's method of ovarian tracheation (Detinova 1954, 1959, 1962). The ovaries were then examined in a drop of distilled water under X100 of a Propper compound microscope.

All dissections were done within one week of capture and the specimens were kept frozen in dry ice until dissected. Corbet (1961b) showed that mosquitoes were suitable for dissection after being kept frozen for three months. I found that it was possible to use Detinova's method on ovaries which had been stored dry on a slide for a year.

Males were counted and identified to genus only.

Except for Malaise trap captures all mosquitoes were killed by freezing with dry ice.

1.2.4. Ageing by external features

Detinova (1959, 1962) Corbet (1959) and Southwood (1966) have reviewed methods for assessing the age of adult female mosquitoes by external characters. I tested two of these methods, the presence of parasitic mites and external wear.

1.2.4.1. Presence of parasitic mites - Gillet (1957) suggested that parasitic mites on female mosquitoes indicated nulliparity. He assumed that these were acquired on emergence from the pupa and lost on oviposition. Detinova (l.c.) pointed out that not all waters contained mites and that not all mites left at first oviposition. Corbet (1963)

Table 1 Numbers of parous and nulliparous mosquitoes with parasitic mites attached at George Lake in 1966.

Species	Parous	Nulliparous	Unknown	Total
Culiseta inornata			1	1
Aedes cataphylla		1		1
A.communis		2		2
A.excrucians	2	12	1	15
A.fitchii	1	3		4
A.pionips	2	1		3
A.punctor	5	4	2	11
A.riparius		3		3
A.sticticus			1	1
Unidentified	1			1
Total	11	26	5	42
No. examined	280	449	209	983
% with mites	3.9	5.8	2.4	4.3

found that for ten Uganda species of mosquitoes the species of mite was important. Some species which sought their prey on the surface could attack the ovipositing females.

There were many larval mites on female mosquitoes at George Lake in 1966. I recorded the numbers of mosquitoes dissected for parity to see if there was any correlation. These mites are conspicuous, remain on dried specimens and could be used by untrained personnel; thus if an estimate of the parity rate can be obtained from their presence this method would be most useful to mosquito control organizations. I know of no study of this method in North America.

Table I shows the distribution of parasitic mites on mosquitoes taken by all methods at George Lake during the summer of 1966. Only nine of the 28 species found and less than 5% of the specimens examined had mites attached. The presence of parasitic mites on female mosquitoes is thus useless for determining parity rates here.

1.2.4.2. External wear - Perry (1912) proposed a method for determining the age of anophelines by the condition of the scale fringe around the wings. Later workers (Detinova *l.c.*, Corbet 1959) have shown that this depends more on the conditions of life than on the age of the insect. Corbet believed that this method might be useful for distinguishing newly emerged females and wing fray has proved useful for assessing the mean age of a sample of tsetse flies (Buxton 1955).

To see if it was possible to use the appearance of the whole mosquito, rather than the wing alone, six arbitrary wear categories

were established :-

0. Pristine, unrubbed, very fresh appearance.

1. Very good, unrubbed, but not so fresh.

2. Good, some mesonotal scales missing but pattern clearly discernible.

3. Fair, mesonotum rubbed, but species still identifiable by scale pattern.

4. Rubbed, mesonotum with most scales missing, species not identifiable by scale pattern.

5. Bald, almost all scales missing, black legged *Aedes* sp. rarely identifiable.

Since some traps damaged their catches more than others, only the Malaise and Malaise + CO_2 traps were used in this test.

Table 2 shows the number of pars and nullipars in each category and fig. 3 the relationship between percentage parous and wear category. Though there is a clear relationship, it is different in the different trapping methods and did not prove reliable for assessing the parity rate of a sample. Four samples were drawn from Malaise trap captures and four from Malaise + CO_2 captures and tested against the appropriate and the combined curves. The results are shown in Table 3. These show that the curve for Malaise + CO_2 gives a good estimate of the parity rate when it is over 80% but only for mosquitoes taken by this method. The curve for Malaise traps and the combined curve did not give useful estimates. This method is unreliable probably because it is an attempt to estimate physiological age from an attribute correlated to actual age. External wear will very probably

Table 2 Numbers of parous and nulliparous mosquitoes in different wear categories taken in Malaise (M) and Malaise + CO_2 traps at George Lake 1966 (all species).

Wear Category	Parous			Nulliparous			Total Examined		
	M	M+CO_2	Total	M	M+CO_2	Total	M	M+CO_2	Total
0	6	16	22	21	26	47	27	42	69
1	10	35	45	21	27	48	31	62	93
2	17	44	61	32	8	40	49	52	101
3	4	21	25	4	1	5	8	22	30
4	3	8	11	2	0	2	5	8	13
5	2	1	3	0	0	0	2	1	3
Total	42	125	167	80	62	142	122	187	309

See also Table 3.

Table 3 Estimates of parity rate of mosquitoes in samples from external wear categories.

(Samples chosen at random from Malaise and Malaise + CO_2 captures).

Sample	No. Mosquitoes	Mean Wear	Observed Parity Rate %	Expected Parity Rate %	*
1 (Malaise)	32	2.3	29	40[1]	66
2 (Malaise)	20	2.6	75	45[1]	71
3 (Malaise)	10	1.2	50	31[1]	51
4 (Malaise)	39	3.6	61	57[1]	84
5 (M+CO_2)	16	2.1	50	86[2]	64
6 (M+CO_2)	20	1.6	65	74[2]	56
7 (M+CO_2)	25	1.8	80	79[2]	59
8 (M+CO_2)	20	2.3	90	88[2]	66

1 From curve for Malaise trap in Fig. 3

2 From curve for M+CO_2 in Fig. 3

* From curve for combined Malaise and Malaise + CO_2 in Fig. 3.

give a useful estimate of actual age but this could only be demonstrated by extensive field marking experiments.

1.2.4.3. Discussion - It is clear from the above and the work of previous authors (Corbet 1959, Detinova 1959, 1962) that estimates of the physiological age of mosquitoes without dissection are unreliable. Unfortunately many dissection techniques are difficult (eg. Polovodova 1949) or enable the estimation of age for only a small proportion of the sample (eg. Gillies 1956, Van Dijk 1966). Fortunately Detinova (1945, 1959, 1962) has provided a method by which pars and nullipars can be easily and accurately separated, provided their ovaries are in early stage III of Christophers or earlier. The Polovodova technique should be used whenever possible as it enables not only parity rate but also the exact number of egg batches laid by each female to be determined, but it requires a skilled staff.

2. OBSERVATIONS ON BIOLOGY.

2.0 Diversity

Twenty nine species of mosquitoes have been recorded from the George Lake field site. Nineteen species were taken in 1965, twenty seven in 1966 and twenty five in 1967. The species found and their relative abundance are shown in Tables 4 and 5. Pucat (1965) records 38 species of Culicinae from Alberta.

Seven species made up 80% of the 1966 collections. These were :- *Culiseta inornata* (Williston), *Aedes excrucians*, *A.fitchii*, *A.communis*, *A.punctor*, *A.riparius* and *A.vexans*. This preponderance of a few species was expected from the work of Williams (1964) and has been recorded in northern mosquitoes by Happold (1963, 1965a) in Alberta and by Skiersca (1965) in Poland as well as by other authors elsewhere.

The coefficient of diversity (Fisher *et al*. 1943) was 5 ± 0.04 in 1966 and 3 ± 0.02 in 1967, even though the number of species found was almost the same. It appears that this coefficient is a function of sample size as well as population size in a population with a large number of individuals, but a limited number of species. The coefficient of diversity is of use in comparing different areas or traps sampled at the time, as has been shown by Williams (1964) using the data of Rowe (1942) for mosquitoes taken in light traps in several cities in Iowa. It is also useful for comparing captures in the same trap in different years, provided the samples are similar in size or the number of possible species is very large, as in the Lepidoptera studied by Williams (1964).

Table 4 Mosquito species collected at George Lake in 1965, 1966 and 1967, with their relative abundance.

Genus Anopheles Meigen, 1818

A.earlei Vargas, 1943 c

Genus Culiseta Felt, 1904

Subgenus Culiseta Felt, 1904

C.alaskaensis (Ludlow), 1906 fc *

C.inornata (Williston), 1893 a *

Subgenus Culicella Felt, 1904

C.minnesotae Barr, 1957 fc

C.morsitans (Theobald), 1901 p ‡

Genus Culex Linnaeus, 1758

Subgenus Culex Linnaeus, 1758

C.tarsalis Coquillet, 1896 p * 1

Subgenus Neoculex Dyar, 1905

C.territans Walker, 1856 c *

Genus Mansonia Blanchard, 1901

Subgenus Coquillettidia Dyar, 1905

M.perturbans (Walker), 1856 c

Genus Aedes Meigen, 1818

Subgenus Aedes Meigen, 1818

A.cinereus Meigen, 1818 c *

Subgenus Aedimorphus Theobald, 1903

A.vexans (Meigen), 1830 Va * 1

Table 4 cont.

Subgenus Ochlerotatus Lynch Arribalzaga, 1891

A.canadensis (Theobald), 1901 r *

A.cataphylla Dyar, 1916 p *

A.communis (De Geer), 1776 c *

A.diantaeus Howard, Dyar & Knab, 1913 p + 1

A.dorsalis (Meigen), 1830 p * + 1

A.excrucians (Walker), 1856 Va *

A.fitchii (Felt & Young), 1904 a *

A.flavescens (Muller), 1764 fc

A.hexodontus Dyar, 1916 r

A.implicatus Vockeroth, 1954 c *

A.intrudens Dyar, 1919 fc *

A.pionips Dyar, 1919 fc *

A.pullatus (Coquillet), 1904 r

A.punctor (Kirby), 1837 a *

A.riparius Dyar & Knab, 1907 c *

A.spencerii (Theobald), 1901 p

A.sticticus (Meigen), 1838 fc *

A.stimulans (Walker), 1848 p

A.trichurus (Dyar), 1904 p

Key

Va - Very abundant	fc - Fairly common	* - taken in 1965
a - Abundant	r - Rare	+ - not taken in 1966
c - Common	p - Present	1 - not taken in 1967

Table 5 Numbers of mosquitoes identified at George Lake in the spring and in summer of 1966.

Species	No. Identified	% of total Identified
1. *Anopheles earlei*	41	1.8
2. *Culiseta inornata*	187	8.4
3. Other *Culiseta*	63	2.8
4. *Culex territans*	43	1.9
5. *Mansonia perturbans*	36	1.6
6. *Aedes cinereus*	62	2.8
7. *A.communis*	75	3.3
8. *A.excrucians*	518	23.3
9. *A.fitchii*	199	8.9
10. *A.implicatus*	47	2.1
11. *A.punctor*	188	8.4
12. *A.riparius*	80	3.6
13. *A.vexans*	517	23.3
14. Other *Aedes*	186	8.4
Total *Aedes*	1871	83.5
Total caught	2459	
Number of species	28	
Coefficient of diversity (Williams α)	5	

2.1 Notes on the mosquito species taken or likely to be found at George Lake.

Genus *Anopheles* Meigen, 1818 - only one species of *Anopheles* is recorded from Alberta.

Anopheles earlei Vargas, 1943. This is a member of the widespread "*Anopheles maculipennis*" complex and until recently was confused with a pacific coast species *A.occidentalis* Dyar and Knab. It is distributed over much of the northern U.S.A. and Canada north to Labrador and Alaska; probably all records of *A.occidentalis* from east of the mountains refer to this species. It is fairly common at George Lake.

There is believed to be only one generation per year in Alberta (Happold 1963). Overwintering appears to be by nulliparous females, which hibernate in basements and animal burrows (Shemanchuk 1965). They leave their hibernation sites in early spring and oviposit soon after. At George Lake adults emerged in late July in 1966 but in late June in 1967. The adult females are long lived and overwintered females could still be found in late July 1966. Dissections for parity rate confirmed that there was only one generation in 1966 (fig. 21) but the situation in 1967 was not clear as nullipars predominated in late June. Fig. 22 shows the parity rate in 1967 compared with *Culiseta alaskaensis* (Ludlow) which has only one generation. No hibernation sites were found at George Lake but a series of females taken at animal burrows by Shemanchuk at Rimbey, Alberta in October, 1966, were all nulliparous.

Larvae of this species were found in a sedge meadow along with

occurs in both forest and open country and has successfully adapted to urban conditions, forming a large proportion of the mosquitoes breeding in Edmonton. It was common at George Lake in 1966, when it was most abundant near the lake shore, but was not taken after the second week in May in 1967. Happold found it to be rare at Flatbush; he found no larvae and very few adult females.

This species overwinters as an adult female, but has several generations in a summer. Wada (1965) found oviposition in Edmonton continued into mid August. Unfortunately most of the females taken at George Lake were gravid so no confirmation of generation number was possible. Malaise trap captures in 1966 show three peaks, which suggests two generations: one peak in early May, when overwintered females leave hibernation sites, one peak in early August, when the adults resulting from eggs laid by the overwintered females emerge and one in September, which may represent a second generation. Larvae have been found in woodland pools in Edmonton but none have been found at George Lake.

Culiseta minnesotae Barr, 1957 - This is a recently described species which is often confused with *Culiseta morsitans* and has not previously been reported from Alberta. I did not distinguish between the two species in 1965. All 1966 specimens which I preserved were *C.minnesotae* but it is possible that a few *C.morsitans* may have been taken, so that fig. 17 may include a few *C.morsitans*.

C.minnesotae hibernates as an adult female, which leaves winter quarters early in the spring, being recorded in the first week of May

1967, before C.alaskaensis. The distribution of this species is not yet well known. Stone (1965) records it from Minnesota, Utah, Ontario, New Jersey and Massachussets. Curtis (1967) states it has been recorded from the borders of British Columbia but not yet in that province. Probably many records of C.morsitans will prove to be C.minnesotae. Barr (1958) states that it does not appear to take human blood.

Culiseta morsitans (Theobald) 1901 - This is a holarctic species with a more or less northern distribution. It is not common at George Lake, where only five specimens have been definitely identified. Elsewhere in Alberta I have seen specimens of this species from the Cypress Hills, Edmonton, and Flatbush.

Very little is recorded of the biology of this species in North America. In Europe, Marshall (1938) and Wesenberg-Lund (1921) found that it overwinters as a larva, and unlike other Culiseta species it oviposits on wet mud, laying eggs singly instead of in rafts. Howard et al. (1915) considered it hibernated as an egg in North America but this does not seem to be so, and there is no study of its life history. Stone et al. (1959) suggest that the North American form may be different to the palearctic one, but this may be due to confusion with C.minnesotae. At George Lake in 1967 this species appeared in late June, and one dissected was nulliparous.

Genus Culex Linnaeus, 1758 -

Culex restuans Theobald, 1901 - This species has not been found at

George Lake but was taken by Klassen (1959) in Edmonton.

Culex tarsalis Coquillet, 1896 - Two specimens of this common prairie species were taken in 1966. They had probably migrated into the field site from surrounding open lands. This species may be extending its range north in Alberta, Hocking (pers. comm.) informs me that it has increased in abundance in Edmonton in the last ten years.

Culex territans Walker, 1856 - This is a holarctic species which until 1949 was confused with C.apicalis Adams in North America. It is probable that all records of C.apicalis east of the mountains and North of Utah refer to C.territans. Possibly because it rarely bites man, it is recorded as rare in most regional mosquito records (Happold 1963, 1965a, Curtis 1967, Steward and McWade 1961). It is believed to feed mainly on cold blooded vertebrates but Means (1945) has recorded it feeding on man. It was fairly common at George Lake in 1966 and 1967, and was one of the first mosquitoes to leave winter quarters. In 1967 C.territans was the first mosquito taken, one specimen being taken in a Malaise trap in April, before the snow had completely melted.

From seasonal distribution data it appears that there were two generations in 1966 (fig. 18), but dissections were too few to confirm, though they do support this.

Genus Mansonia Blanchard 1901 - This is a mainly tropical genus; two species penetrate into northern regions, one in Eurasia and one in North America.

Mansonia perturbans (Walker) 1856 - This widespread North American

species was first taken in Alberta at Flatbush by Happold in 1961, (Happold 1963) and this is still the only published locality (Pucat 1964, 1965). I have seen specimens from Edson and P. Shera (unpublished report) has recorded it from Elk Island National Park. At George Lake it was not found in 1965, but was fairly common in 1966 and had just appeared in 1967 when work was stopped. It is probably common and widespread over the forested parts of Alberta. There appears to be only one generation per year and this the only Canadian mosquito definitely known to overwinter as a larva (Happold 1963). As yet no larvae have been found in Alberta.

Adult females of this species are reputed to be fierce biters, but were not numerous enough to be a nuisance at George Lake. Happold (*l.c.*) at Flatbush and Burgess and Haufe (1960) in Ontario found this species abundant in the forest canopy.

Genus Aedes Meigen 1818 - This is the predominant mosquito genus in Alberta and in most northern regions. It includes 70% of the species and 80% of the specimens caught at George Lake. The genus is distributed from the equator to the limit of land in the north and is found on many oceanic islands.

Three subgenera, *Aedes* Meigen, *Aedimorphus* Theobald, and *Ochlerotatus* Lynch Arribalzaga, are found in Alberta.

All Alberta *Aedes* species overwinter as eggs and with the possible exceptions of *A.vexans* and *A.dorsalis* (Meigen) there is only one generation per year. Brust (pers. comm.) informs me that diapause is not

obligatory in the eggs of A.sticticus, so this species may also be multivoltine if the season permits.

Aedes (Aedes) cinereus Meigen, 1818 - This small holarctic species is common in central Alberta. It is a woodland species which is also common in Poland (Skiersca 1965). It is common at George Lake, where it is a late-appearing species reaching an adult population peak in July and early August in 1966. I noticed that it is a low flier and bites mainly below the knee and around the ankles.

Aedes (Aedimorphus) vexans (Meigen) 1830 - This appropriately-named species has one of the widest and most unusual ranges of any mosquito, being found in the Palearctic, Nearctic, and Oriental regions and also in Fiji, Samoa and New Caledonia (Stone et al. 1959). Muspratt (1955) has described an isolated population in the Transvaal, South Africa, which appears indistinguishable from the others. It was very common at George Lake in 1965 and 1966 but was not found there in 1967, though it may have appeared after work stopped. It was taken in June 1966.

Rempel (1953) suggested there were two forms of A.vexans in Saskatchewan, a large form in the prairies and a smaller one in the parklands and forest.

A.vexans is a migratory species, capable of flying long distances. Horsfall (1955) records many instances of migration in temperate regions and de Meillon and Khan (1965) have recorded a large migration in Burma. A result of this migratory tendency, is that this species is often a major pest species in cities like Edmonton with efficient control programs, as it migrates in from breeding sites which may be several

miles from the city. Clark and Wray (1967) have studied the influx of A.vexans into Des Plaines, Illinois, and provided a method of predicting invasions.

A.vexans is a late emerging species with a 1966 population peak in late summer. The adult females continued well into September 1966 and larvae were taken in late August. Stage et al. (1938) recovered a marked female 55 days after release.

In the southern part of its range it is multivoltine, but the number of generations in northern parts is not clear, as the eggs do not hatch simultaneously; some may require several floodings before hatching (Horsfall 1955), giving rise to broods. Gjullin et al. (1950) found the eggs remained viable for three to four years if kept moist.

Nullipars were found from June to the end of August 1966 and predominated up to late August, indicating that emergence took place in June, July, and early August, but there was no evidence of more than one brood.

Subgenus Ochlerotatus Lynch Arribalzaga, 1891 - This is the dominant subgenus in northern regions, but also occurs in the tropics. In North America this subgenus extends further north than any other culicid. Two species, A.nigripes (Zetterstedt) and A.impiger (Walker), occur within 500 miles of the pole. Nineteen species have been recorded at George Lake, and Pucat (1965) records 25 from Alberta.

Aedes campestris Dyar and Knab 1907 - This species has been recorded at Edmonton (Klassen 1959; Wada 1965), but not yet at George Lake.

A.canadensis (Theobald) 1901 - This species is widespread in the

forested parts of North America. It is not common at George Lake. Rempel (1950) found it to be fairly common in the aspen grove parkland of Saskatchewan. It is a late emerger; at George Lake it appeared at the end of June in both 1966 and 1967.

Aedes cataphylla Dyar, 1916 - This holarctic species is confined to western Northern America in the Nearctic (Stone 1965). It is not common at George Lake, but is often a major pest species in Edmonton (Klassen l.c.; Klassen and Hocking 1963). It is one of the first species to emerge, Klassen found emergence completed by 19 May, 1958, at Edmonton.

Aedes communis (De Geer) 1776 - This is an important woodland species with a circumboreal distribution and is a well known pest species in Europe and North America. Chapman and Barr (1964) have described a subspecies A.communis nevadensis Chapman and Barr from the western U.S.A. and two larval forms of the typical subspecies. All larvae examined from Alberta belonged to the eastern form. Hocking (1954) described an autogenous form from Churchill on Husdon's Bay in which autolysis of the flight muscles takes place. The species is common at George Lake.

It is a fairly early emerging species; in 1966 a population peak of adult females occurred in early June. Nullipars predominated to late June, indicating that some emergence took place up to then.

Aedes diantaeus Howard, Dyar and Knab, 1917 - This species has a wide distribution in the boreal forests of the old and new worlds, but it is seldom abundant (Vockeroth 1954b). In Alberta it has only been recorded from Flatbush (Happold 1963; Pucat 1964). A single specimen

was found at George Lake in 1966.

Aedes dorsalis (Meigen) 1830 - This species occurs in the grasslands of the Palearctic and Nearctic regions. It is abundant in southern Alberta but uncommon north of Edmonton. One specimen was taken at George Lake in 1965.

Khelevin (1958) has shown that diapause in the egg of this species is facultative and it can have several generations per year. Like A.vexans it is a migratory species (Horsfall 1955).

Aedes excrucians (Walker) 1856 - This is a holarctic woodland species with a somewhat more southerly distribution than A.communis. Together with A.vexans, it was one of the two most abundant species at George Lake in 1965 and 1966. It was also abundant in 1967, but work stopped before it reached population peak. It is a fairly early emerger, first appearing in the last week in May 1966 but not till the second week in June 1967. The emergence period appears to be prolonged as nullipars predominated till mid July and could still be found in early August 1966. The adult females were found up to the end of August but none were taken in September 1966. Matheson (1944) records a single instance of larvae being found in September in New York. It is a persistent biter, and is a major pest species in central Alberta.

Aedes fitchii (Felt and Young) 1904 (Frontispiece) - This species is confined to North America, where it has the same range as A.excrucians. It is common in central Alberta. At George Lake it appeared in early June 1966, nullipars predominated until mid July and were found till mid August, indicating a prolonged emergence period. Adult females

were taken up to the end of August but were not taken in September either in 1965 or in 1966.

It is an important pest species in central Alberta.

Larvae were found in a pool in a spruce grove on the western fence of the George Lake field site along with those of A.implicatus in May 1966.

Aedes flavescens (Muller) 1764 - This species occurs in grassland areas of Eurasia and North America. It is common in central Alberta and fairly common at George Lake. Specimens taken on the field site had probably migrated in as it is an open country species. Hearle (1929) considered it to be the most numerous mosquito on the Canadian prairies. Happold (1963) did not find it in the forest at Flatbush but found it common in an alfalfa field.

Adult females were taken from early June to mid August 1966 at George Lake. Nullipars were found till early July. A single male was taken in June 1967, when females were more abundant than in 1966.

Aedes hexodontus Dyar, 1916 - This tundra and open country species was first recorded from Alberta by Wada in 1964 at Edmonton, (Wada 1965). It was not common at George Lake. It is an early species and was not found after June in either year.

Aedes implicatus, Vockeroth 1954 - Prior to 1954 this species was called A.impiger (Walker) 1848, but Vockeroth (1954a) showed that the name A.impiger should apply to A.nearticus Dyar 1919, and the species which had been called A.impiger was unnamed. He named it A.implicatus.

It is a boreal forest species, confined to North America, and

occurs north almost to the tree line. It is locally common in central Alberta, being common at George Lake but rare at Flatbush. In late May and early June 1967 this species was the most abundant Aedes at George Lake.

It is an early emerger, the adult females reaching a population peak in mid June in both 1966 and 1967. There was some indication that a second brood occurred in late July 1966, as pars predominated in late June and early July, but the three specimens dissected in late July and early August were nulliparous. In 1967 only nullipars were taken in May but pars predominated in late June and the numbers taken began to decline in mid June. Neilsen and Rees (1961) believed this to be a short lived species; if so then second broods are needed to account for nullipars occuring in late summer.

In early May 1966 larvae were found in pools, in ruts, in the road near the campsite and in a pool on the western boundary along with those of A.fitchii.

Aedes increpitus, Dyar 1916 - This species has been taken at Edmonton by Klassen and Wada, but has not yet been found at George Lake.

Aedes intrudens Dyar, 1919 - Another species with a circumboreal distribution, it was common at Flatbush and relatively rare at George Lake in 1966, but common there in 1967.

It is an early species, with a population peak in late spring and only pars were taken in July 1966. Happold recorded it as the most important Aedes species in buildings at Flatbush. At George Lake only one specimen was taken in the trailer in 1966 but it was prominent

indoors in spring 1967. Matheson (1944) says of this species: "Dyar states that this species readily invades houses, but I have never taken them in houses though I have found them abundantly in wooded areas throughout the season".

Aedes pionips Dyar, 1919 - This nearctic species is found in Canada and the western U.S.A. Jenkins (1948) found it to be one of the most abundant species in Alaska. It is rare at George Lake.

It is generally considered to be a late emerger (Carpenter and LaCasse l.c.) but at George Lake in 1966 the population peak appeared to be in early summer, adult females continued into August, nullipars were found in late July.

Aedes pullatus (Coquillet) 1904 - This species is confined to the western mountains and to the Ungava peninsula and South Baffin Island in North America. It also occurs in Europe where it is not a mountain species. In Alberta it is common in the Rocky Mountains. Klassen and Wada did not find it at Edmonton but in some years it is common there (Hocking, pers. comm.). It was rare at George Lake, and only found there in late May and early June.

Jenkins and Knight (1950) found it to be one of the most abundant species at Great Whale River on the east coast of Hudson Bay and Vockeroth (1954b) states that the eastern forms may be different from the western, though no morphological differences could be found.

Aedes punctor (Kirby) 1837 - This is an important woodland species with a holarctic distribution. It is a major pest species in both North America and northern Eurasia. It is common in central Alberta, being

the major black-legged Aedes species at both George Lake, Edmonton and Flatbush.

In 1966 adult females were taken from late May into September, the population peak being in early June. In 1967 this species reached its peak somewhat later than A.implicatus, becoming the most abundant species in the third week in June. In 1966 there was a small secondary peak in early August, which may have signified a second brood, but the few dissections done at this time did not confirm this, being mainly parous. Nullipars predominated up to early July and were found up to mid August, so it is probable some emergence took in each summer month in 1966.

Aedes riparius Dyar and Knab 1907 - This species occurs in western North America and northern Eurasia. It is mainly an open country species but also occurs in woodlands. It is common in central Alberta.

In 1966 it was not found until late June when it occurred in fairly large numbers, which possibly indicates it did not breed in the area. Nullipars predominated in June and July and were found in August. In 1967 this species was taken in late May and was the most abundant band-legged Ochlerotatus species till the end of June when A.excrucians began to reach peak emergence.

Aedes spencerii (Theobald) 1901 - This is a prairies species, confined to western North America. It is among the most numerous species in southern Alberta but rare north of Edmonton. One specimen was taken at George Lake in August 1966 and several in late May 1967.

A.sticticus (Meigen) 1838 - This is a holarctic species which extends

its range south to the Gulf of Mexico in North America. It is locally common in central Alberta being fairly common at George Lake and rare at Flatbush.

Adult females were taken from late May to the end of July and nullipars to mid July in 1966.

Aedes stimulans (Walker), 1848 - This species has much the same range as A. fitchii. It is common over much of the forest country of Canada, but appears to be rare in central Alberta. Only four specimens have been definitely identified at George Lake and Happold did not find it at Flatbush.

Aedes trichurus (Dyar), 1904 - This is a woodland species found in the northern U.S.A. and southern Canada. In Alberta it occurs as far north as Beaverlodge (Rempel 1950). It was rare at George Lake.

2.2. Seasonal distribution

Happold (l.c.) has discussed the seasonal distribution of mosquitoes at Flatbush, where most of the important species found at George Lake occur, and the George Lake findings are in agreement with his.

Figure 17 shows the 1966 distribution of the commoner species in Malaise trap catches corrected to 100 hours running time and figure 18 shows the uncorrected total catch of some of the less common species.

The mosquito population showed three peaks in 1966; the first in early May when the overwintering females left hibernation; one in early July, representing the peak population of Aedes species; and the third in early August formed by the emergence of those females which enter hibernation and second broods of Aedes. This peak was probably much

more pronounced in 1965, when weather conditions favoured second broods.

Figure 19 shows the changes in the relative abundance of various species as the season progresses. The change in emphasis from non *Aedes* in May to *Aedes* in June, July and August and back to non *Aedes* in September is striking.

In 1965 some species, such as *A.intrudens*, continued into August and pars of *Anopheles earlei* were taken in August. This was almost certainly due to the weather conditions in 1965. Happold (*l.c.*) found that in 1961 *Anopheles earlei* adults survived much longer than in 1962, when the weather conditions appear to have been similar to those in 1965, this may apply to other species as well.

In all three years *Aedes* mosquitoes became abundant each spring approximately at the same time as the poplars flushed.

2.3. Movement into buildings

Unlike tropical areas where disease transmission inside human dwellings is important, there is relatively little information from North America on the movement of mosquitoes into buildings. Matheson (1964) mentions a few species as persistent house enterers and Happold (1964b) has recorded the species he collected indoors at Flatbush.

During June, July, and August 1966 and in May and June 1967 special captures were carried out in a partially screened trailer at George Lake.. In 1966, 112 specimens of 16 species and in 1967, 96 specimens of 12 species were taken in this trailer (Table 6).

In 1966 70% of the indoor catch was composed of *A.punctor*, *A.excrucians*, *A.pionips* and *A.communis*, while in 1967 *Anopheles earlei*,

Table 6 Mosquito species taken indoors at George Lake in 1966 and in 1967 and numbers taken.

Species	Number Caught 1st June-1st Sept. 1966 No.	%	16th May-15th June 1967 No.	%
A.earlei	1	0.9	25	26.0
C.alaskaensis	0	0	5	5.2
C.inornata	1	0.9	0	0
C.territans	0	0	3	3.1
A.cataphylla	1	0.9	0	0
A.communis	10	8.9	5	5.2
A.diantaeus	1	0.9	0	0
A.excrucians	19	17.0	0	0
A.fitchii	8	7.1	0	0
A.hexodontus	5	4.5	3	3.1
A.implicatus	3	2.7	5	5.2
A.intrudens	1	0.9	9	9.4
A.pionips	14	12.5	2	2.1
A.pullatus	0	0	2	2.1
A.punctor	34	30.4	33	34.4
A.riparius	1	0.9	1	1.0
A.sticticus	9	8.0	3	3.1
A.trichurus	1	0.9	0	0
A.vexans	2	1.8	0	0
Unidentified	1	0.9	0	0
Total	112		96	

Aedes punctor and A.intrudens made up the body of the catch. A.hexodontus and A.sticticus were also prominent in both years.

Happold (l.c.) found A.earlei and A.intrudens made up 80% of the indoor catch at Flatbush. In 1967 all A.earlei found indoors at George Lake were taken in May. This may indicate that the overwintered females enter buildings to feed but that the trailer did not provide a good hibernation site. Elsewhere this species is known to hibernate in buildings, especially basements. The most striking difference between the George Lake and Flatbush results was the absence of A.punctor from indoor captures at Flatbush, although it was one of the most abundant local species. It formed over 30% of the indoor catch at George Lake.

In central Alberta, the entry of mosquitoes into buildings depends more on the environment rather than on specific innate tendency to enter buildings as has been recorded in the tropics, where exophilous and endophilous genera and species are recognized (Holstein 1954; Muirhead Thompson 1951).

2.4. Distribution within the study area

Figure 20 shows the relative abundance of the major species at the lake shore and in the forest in 1966. Culiseta inornata and Aedes vexans were more abundant in the lake shore traps and A.excrucians and A.fitchii in the forest traps, the other species were more or less evenly distributed. In 1967 A.implicatus was far more abundant in the forest traps.

2.5. Parity Rate

Figure 21 shows the seasonal distribution of pars and nullipars in the species taken more abundantly in 1966 and figure 22 shows the

parity rate for Culiseta alaskaensis and Anopheles earlei, in the spring of 1967. The distributions in Aedes excrucians and A.fitchii exactly fit those expected for a univoltine species which overwinters as eggs, i.e.: there are two overlapping curves, one in early summer with nullipars predominant and one in late summer with pars predominant. The curve for Anopheles earlei in 1966 fits the expected for a univoltine species which overwinters as an adult female, though the number dissected was small. The 1967 curve, however, indicates that considerable emergence took place in late June and as this appears rather early for the female to enter hibernation it is possible that there was a second generation. The 1967 curve for Culiseta alaskaensis is as expected for a species which overwinters as an adult nulliparous female. The picture for the other species is not so clear.

Shelenova (1959) found that in Russia, Aedes species were generally shorter lived than Anopheles in the same area, few Aedes having passed four gonotrophic cycles, while anophelines often had passed 12 to 29. Carpenter and Neilson (1965) also found few Aedes with more than four dilations in the ovarian ducts in Utah.

Corbet (1961b) and Hamon et al. (1964) have studied differences in activity between pars and nullipars, especially with regard to biting activity. Neither found any significant differences, though Hamon et al. found a modification of the biting cycle after spraying with insecticide had removed the older portion of the population. They concluded that extrinsic factors, such as light intensity and temperature are more important in controling activity of adult female mosquitoes

than the age of the insect.

2.6. Ovarian development and activity

Table 7 shows the stages of Sella and of Christophers in the total catch, in total Aedes species and in the commoner species of mosquitoes. By far the greater proportion of all females caught were in stages 1 and 7 of Sella and I, II or V of Christophers. Thus they were either unfed or gravid, with few in the intermediate stages. Christophers (l.c.) and Clement (1963) have shown that the eggs normally develop to stage II of Christophers and then development stops until a blood meal is taken. This agrees with the findings of Carpenter and Neilson (l.c.) in Utah, where 89% of the active females examined were in stages I and II of Christophers.

A surprising part of the 1966 findings at George Lake was that very few of the resting older females caught in the trailer were gravid or in intermediate stages. In 1967 rats were kept in unscreened cages in the trailer and many specimens of Anopheles earlei as well as Aedes species were found in the intermediate stages of Sella and Christophers (Tables 19-22). This indicates that these mosquitoes enter houses in search of food and if they find it remain to digest their blood meals, but otherwise leave fairly soon. It also indicates their digestion of blood meals is done very close to the feeding site. Carpenter and Neilson (l.c.) found about half the resting females taken in their study were gravid but found very few intermediates.

These findings indicate that there is very little flight activity during intermediate stages of the gonotrophic cycle. This is most

Table 7 Distribution of the stages in the gonotrophic cycle (stages of Sella and of Christophers) in the more important species of mosquito taken at George Lake in 1966.

Species	Stage of Sella 1	2	3	4	5	6	7	Mean	% gravid
Anopheles earlei	26	-	-	-	-	-	3	1.6	10
Culex territans	12	1	-	1	-	-	3	2.2	17
Culiseta inornata	15	1	-	1	2	3	90	6.1	80
Mansonia perturbans	12	-	-	-	-	-	-	1.0	0
Aedes communis	38	-	-	-	-	-	1	1.2	2
Aedes excrucians	198	2	3	-	1	1	5	1.2	2
Aedes fitchii	95	1	1	-	-	-	-	1.0	0
Aedes punctor	83	-	-	1	1	-	-	1.1	0
Aedes riparius	36	-	-	-	-	-	-	1.0	0
Aedes vexans	120	1	1	1	-	-	7	1.4	5
Tot. *Aedes*	707	13	5	4	3	1	17	1.2	2
Total catch	786	18	6	5	4	4	115	1.8	12

Table 7 continued.

Species	Stage of Christophers I	II	III	IV	V	Mean
Anopheles earlei	16	10		1	2	1.7
Culex territans	5	7	1		3	2.3
Culiseta inornata	13	3		9	81	3.8
Mansonia perturbans		10	2			2.1
Aedes communis	14	13			1	1.6
Aedes excrucians	51	132	6	1	5	1.8
Aedes fitchii	23	57	3			1.8
Aedes punctor	39	33	3	1		1.6
Aedes riparius	9	22	4			1.9
Aedes vexans	58	53	1	1	7	1.7
Total *Aedes*	265	403	22	4	17	1.7
Total catch	300	438	27	15	106	2.1

probably because the blood fed or gravid female mosquito is a relatively inefficient flying machine as the weight of the blood meal may exceed the weight of the insect. This little flight activity may apply mainly to woodland species as individuals resting in grassland or tundra will be more likely to be disturbed by passing animals. Corbet (1961a) found that most individuals engaging in "non-specific activity" were in the early stages of Christophers, but Standfast (1965) believed that light trap captures in Australia showed that a considerable part of the population was engaging in "non-specific activity" during the night and interpreted this to mean that there was considerable activity in the intermediate stages of the gonotrophic cycle, but did not record any dissections to support this.

Carpenter and Neilson (l.c.) report that a fair number of biting mosquitoes had ovaries in stage III of Christophers and were nulliparous. They suggest that this is an indication of autogeny and mention that some of the species in which this occurred have been shown to be capable of autogeny by Chapman (1962).

At George Lake in 1966 and 1967 records were kept of specimens in stage I of Sella and stage III of Christophers. Twenty-three were found of which seven were nulliparous, forming 0.007% of all nullipars. These seven consisted of five species: A.communis, A.fitchii, A.intrudens, A.punctor, and A.riparius. Two of these, A.communis and A.punctor were included in those found by Carpenter and Neilson (l.c.) and are mentioned as capable of autogeny by Chapman (l.c.) but the phenomenon appears to be much rarer at George Lake than in Utah where 4% of the

biting females had ovaries in stage III of Christophers.

Eighty percent of the females of Culiseta inornata taken at George Lake in 1965 and in 1966 were gravid. The reason for this is not known but it could indicate some degree of autogeny. No indication of autogeny in this species had been found in the laboratory.

2.7. Retention of eggs by parous female mosquitoes and other ovarian abnormalities

During dissections for parity rate I noticed that several parous females with ovaries of otherwise normal appearance (i.e. they did not have the sac-like appearance of those in females which have just oviposited) had retained eggs in one ovary. The number of eggs retained was usually one but six were found in one Aedes excrucians.

Table 8 shows the species and the number in each with retained eggs. This appears to be a widespread phenomenon as it was recorded in ten species of three genera. It is also interesting to note that the percentage of pars with retained eggs in each year was approximately 7%. The slightly higher proportion in August over June, may be due to older multiparous females having a greater tendency to retain eggs over younger pauciparous females: but this will need further study.

In one parous Aedes punctor taken in a Malaise trap in late June 1967 there was differential development in the ovaries, one being in stage II and one in stage IV of Christophers.

2.8. Nectar feeding by adult females

Hocking (1954) has shown the importance of nectar in the diet of

Table 8 Parous female mosquitoes at George Lake with eggs retained in one ovary.

Species	1965 (August)	1966 (June-August)	1967 (May-June)	Total
Anopheles earlei		1	2	3
Culiseta inornata	2	2		4
C.alaskaensis			1	1
Aedes excrucians		11		11
A.fitchii		1		1
A.flavescens		1		1
A.intrudens	1		1	2
A.punctor		2	3	5
A.riparius		1	2	3
A.vexans	2	5		7
Total	5	24	9	38
Tot. No. Pars.	67	337	139	543
% Pars. retaining eggs	7.5	7.1	6.5	7.0

northern biting flies and lists the species of plants on which mosquitoes have been recorded feeding. During August 1965, summer of 1966 and the spring of 1967, a close watch was kept for any signs of nectar feeding by adult females.

On one occasion in 1965 and on several in 1966, females were observed apparently feeding on Solidago flowers. The one in 1965 and one in 1966 were caught and both were *Aedes excrucians*. Mosquitoes were very alert and difficult to catch when feeding on flowers. No feeding on any other plant species was seen. It was surprising that no mosquitoes were found feeding on the flowers of *Epilobium angustifolium* which was a common source of nectar and often visited by bees especially *Bombus* species. Hocking (per. comm.) has observed mosquito females feeding on the nectar of this species of plant at Devon near Edmonton. Mosquito females have been recorded as feeding on *Solidago* in Alabama (Breeland and Pickard 1961) and in Minnesota by Sandholm and Price (1962). Sandholm and Price found *Aedes vexans* feeding on 39 plant species and they suggest that "Mosquitoes in nature may rely extensively upon nectar for satisfying their biological requirements". Thus, it seems probable that *Solidago sp.* may be of considerable importance to the mosquitoes at George Lake in late summer when this genus is among the most abundant flowers.

2.9. Discussion

The mosquito fauna at George Lake appears to be transitional between the true boreal fauna found at Flatbush and the open country fauna further south. It lies close to the southern boundary of several species

(they may extend further south in the mountains), such as *Culiseta alaskaensis*, and *Aedes diantaeus* and near the northern boundary of others, such as *Culiseta inornata*, *Aedes dorsalis*, and *Culex tarsalis*.

Monroe (1956) has analysed the distributions of North American insects and has put them into several categories. Mosquitoes do not fit into these very well but interesting relationships can be seen. *Aedes diantaeus* and *Anopheles earlei* have distributions equivalent to Type B of Monroe, i.e., Boreal. *Culiseta alaskaensis*, has a combined boreal and mountain distribution. *Culiseta incidens*, *Aedes cataphylla* and *A.pullatus* have extended cordilleran, distributions, i.e., Alaska to Colorado. *Culex tarsalis*, *Aedes dorsalis*, *A.flavescens*, and *A.riparius* have ranges over the great plains. The remainder have distributions which are a combination of Boreal, Mountain, Central and Eastern, meaning they are distributed over most of the continent. *Aedes hexodontus* appears to be one of the few insects with an arctic, alpine, and prairie distribution, occurring on the mainland tundras, above the treeline in the mountains and on the prairies, but not in the forest.

Monroe (*l.c.*) shows that many prairie species of insect extend their ranges far into the boreal forest in the small open "prairies" which are scattered throughout the forest, some occurring as far north as the Mackenzie delta. *Aedes flavescens*, *A.riparius*, and *Culex tarsalis* may fall into this category. These species are probably able to extend northwards as farming increases the acreage of open land.

FIGURE I

SKETCH MAP OF STUDY AREA AND CAMPSITE
GEORGE LAKE FIELD SITE

(Drawn from compass traverse)

ca 50°57'N, 114°06' W

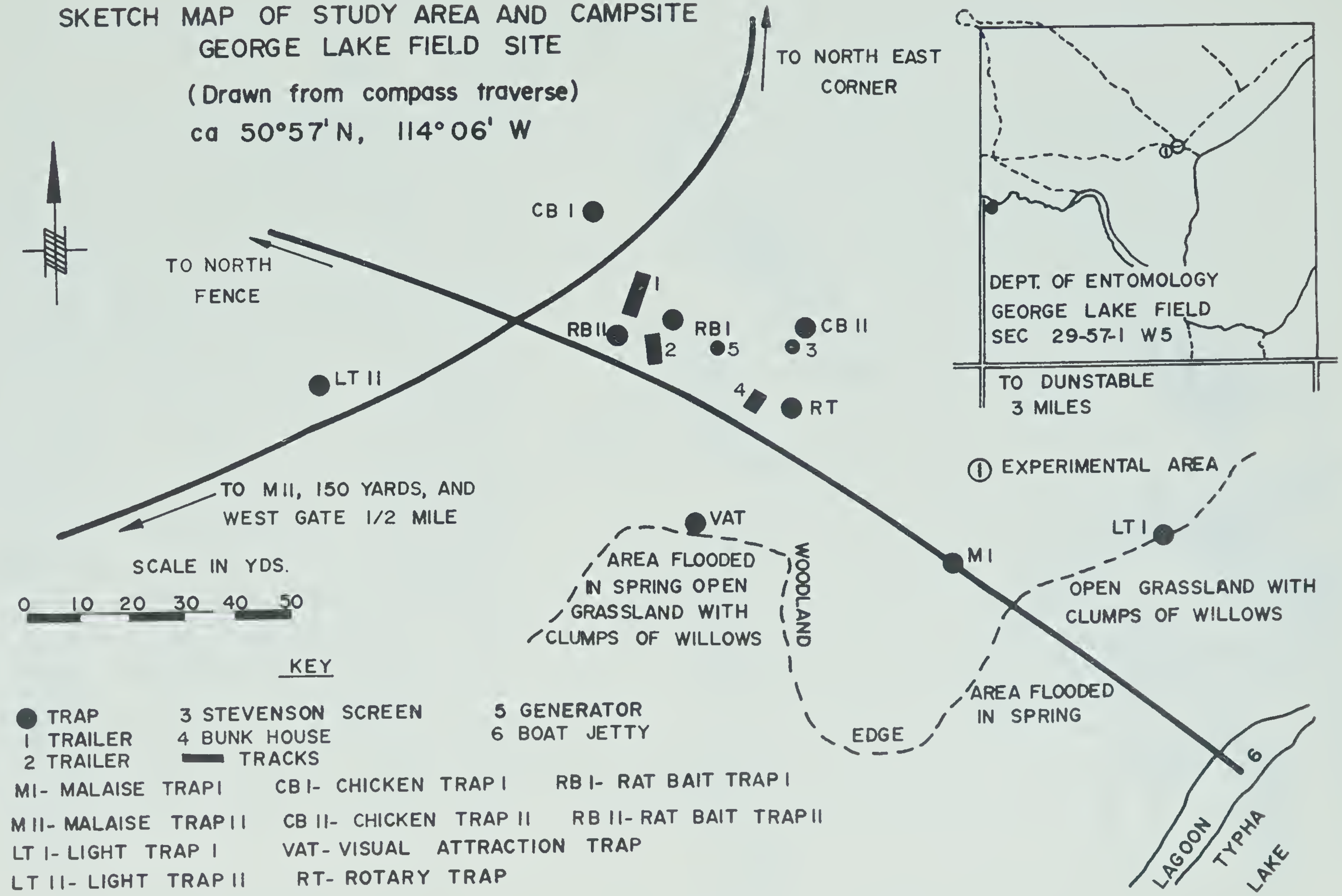
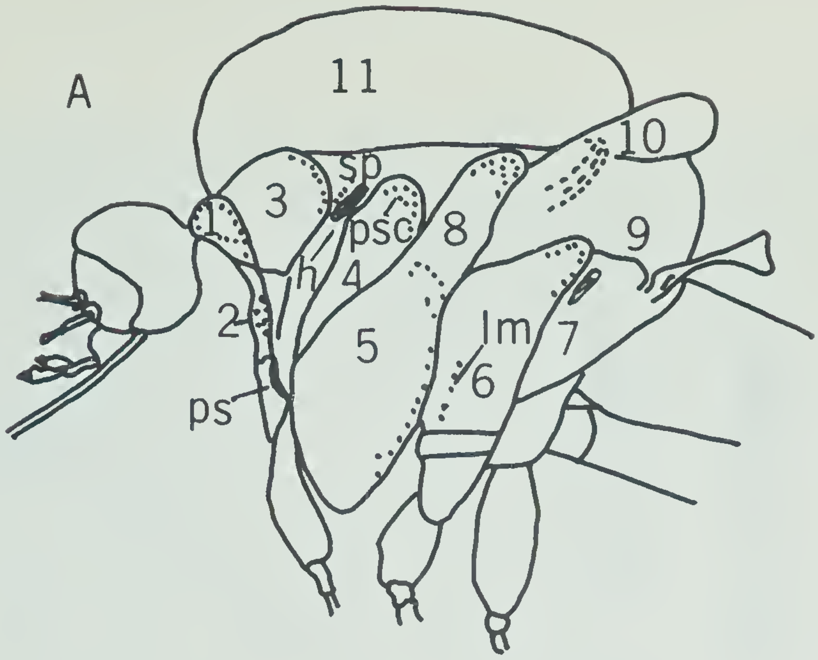


Fig.2 A



B

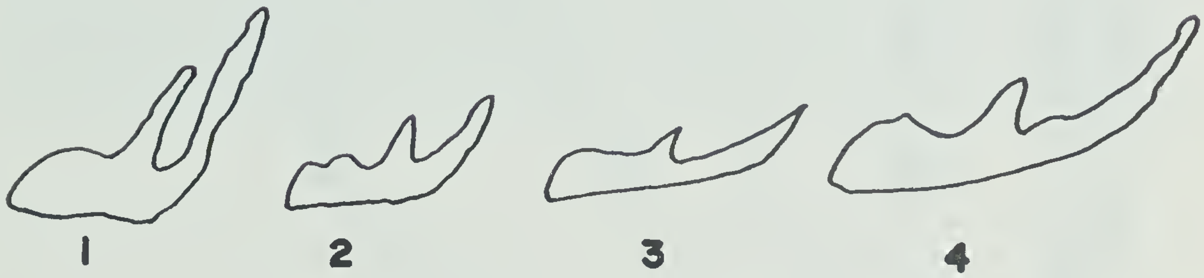


FIG. 2. A. Lateral view of a generalized mosquito thorax. (After Steward and McWade 1961).

B. Claw characters of <u>Aedes</u> species (from Vockeroth 1954b).

KEY A.

1.	Pronotum	7.	Metepisternum
2.	Proepisternum	8.	Prealar area
3.	Post pronotum	9.	Postnotum
4.	Mesanepisternum	10.	Scutellum
5.	Sternopleuron	11.	Mesonotum
6.	Mesepimeron		
h.	Hypostigial scale patch	lm.	Lower mesepimeral bristles
ps.	Post coxal scale patch	psc.	Post spiracular bristles
sp.	Spiracular bristles		

B.

1. <u>Aedes excrucians</u>
2. <u>A.fitchii</u>
3. <u>A.riparius</u>
4. <u>A.flavescens</u>

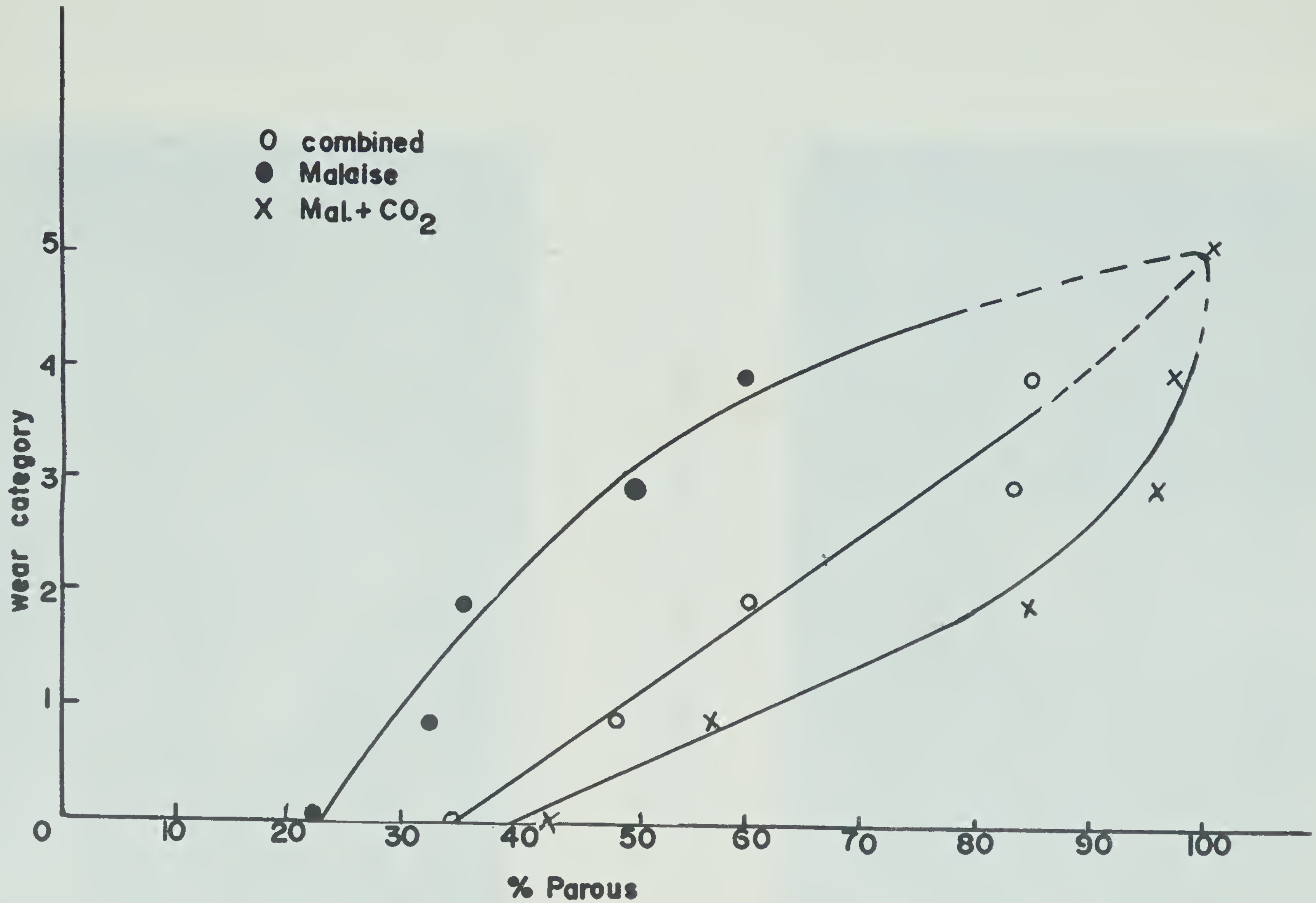


FIG. 3 Relationship between wear category and parity rate in Malaise and Malaise plus CO_2 traps at George Lake. 1 June to 1 Sept. 1966.

FIG. 4 Malaise I from bunkhouse

FIG. 5 Malaise II in April 1967

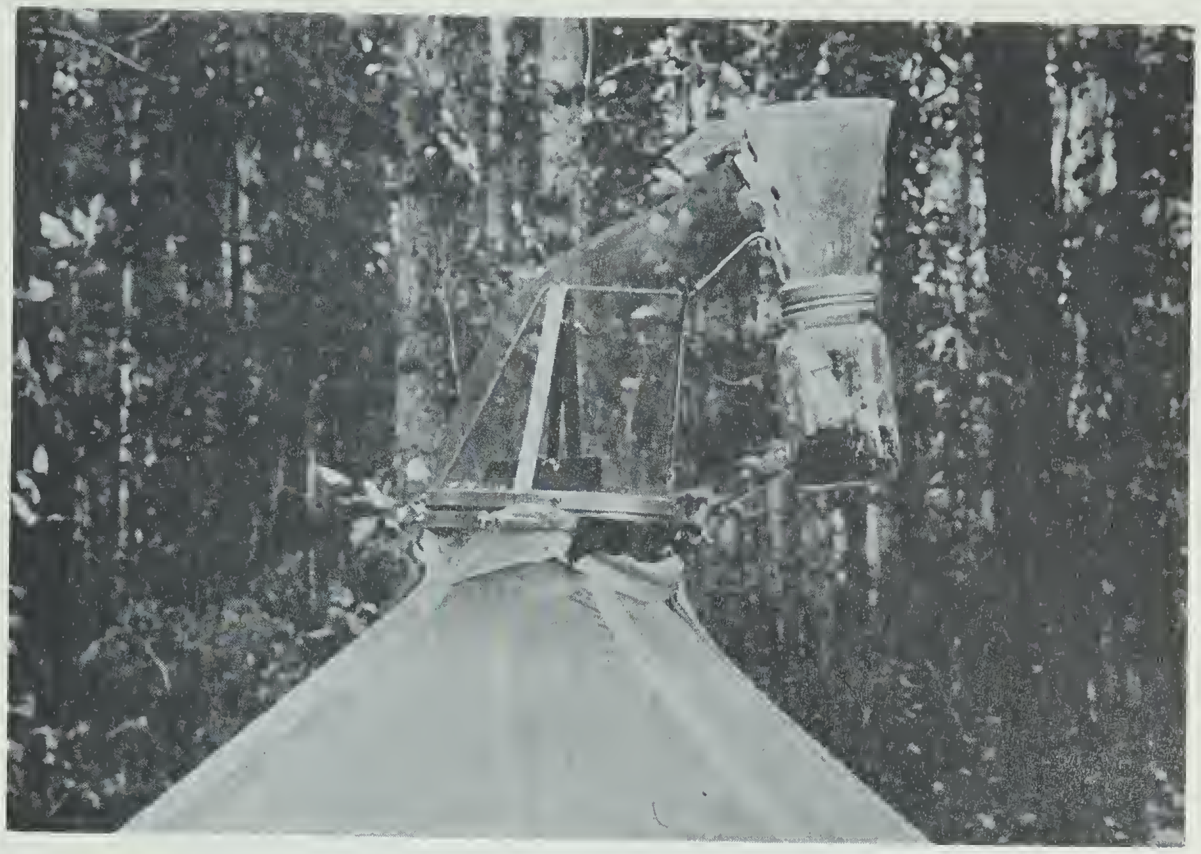


FIG. 6 Catching head of Malaise trap

FIG. 7 Light trap I

FIG. 8 Light trap I showing proximity to the lake

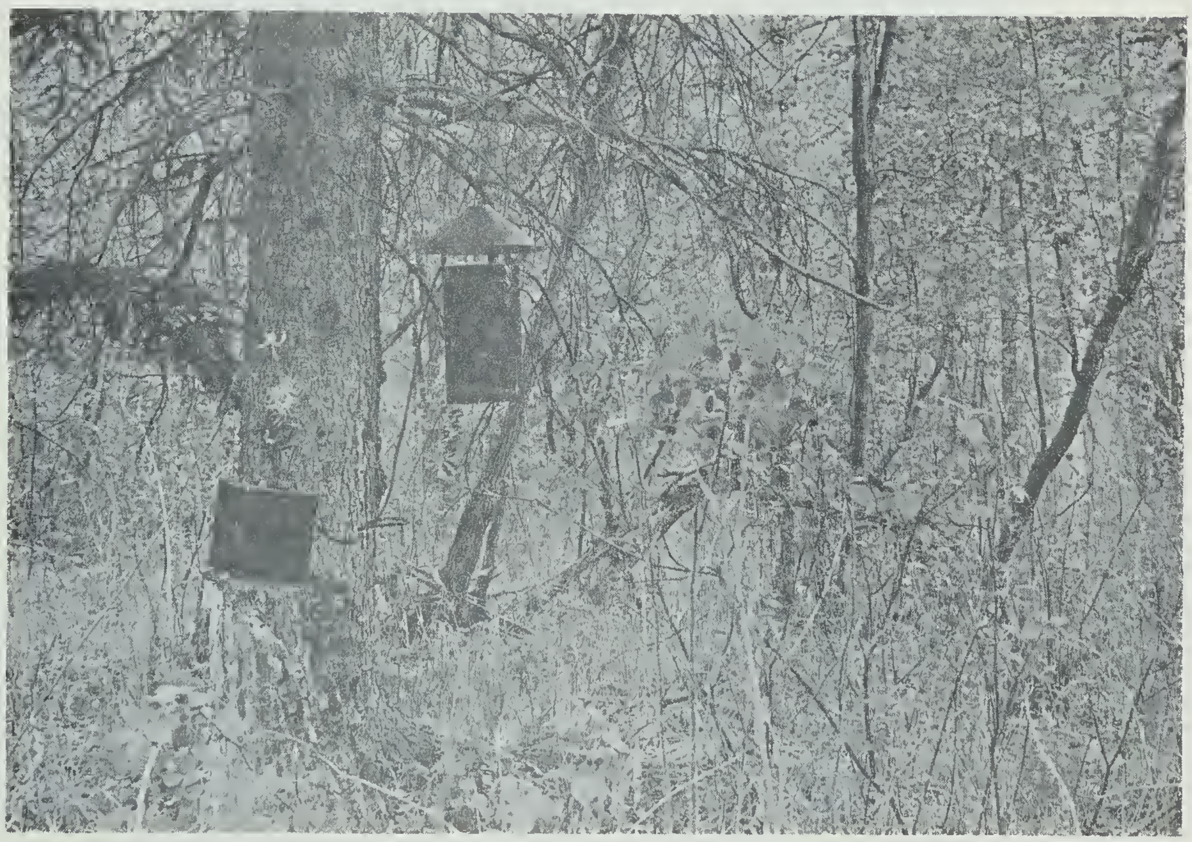


FIG. 9 Light trap II

FIG. 10 Rotary trap

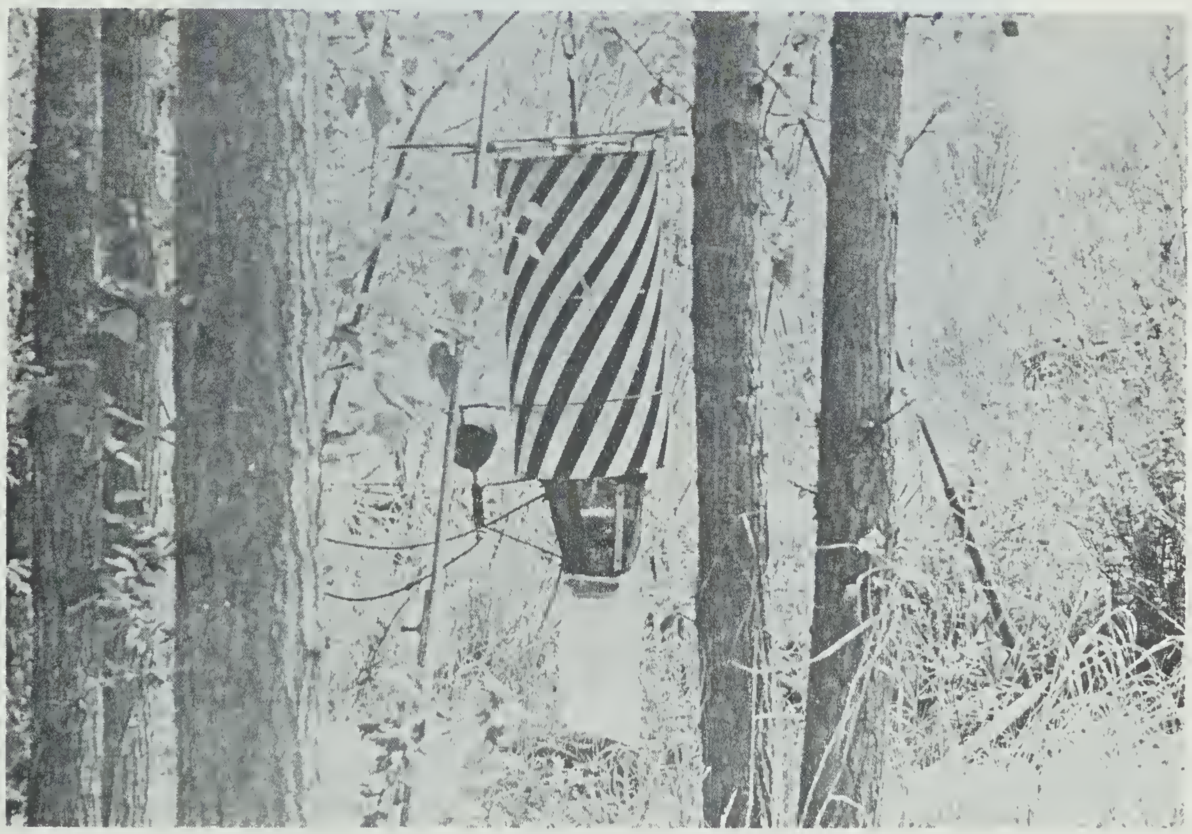


FIG. 11 Visual attraction trap

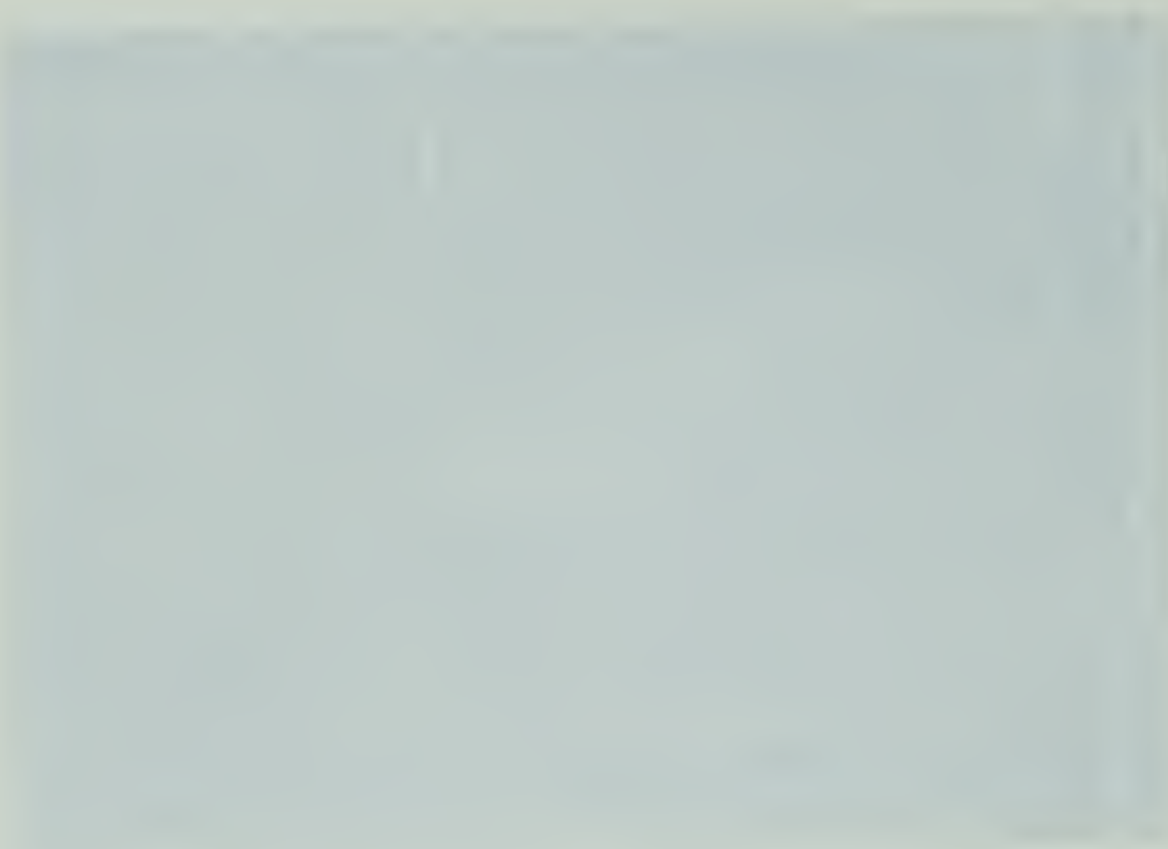


FIG. 12 Malaise I with CO_2 cylinder in place

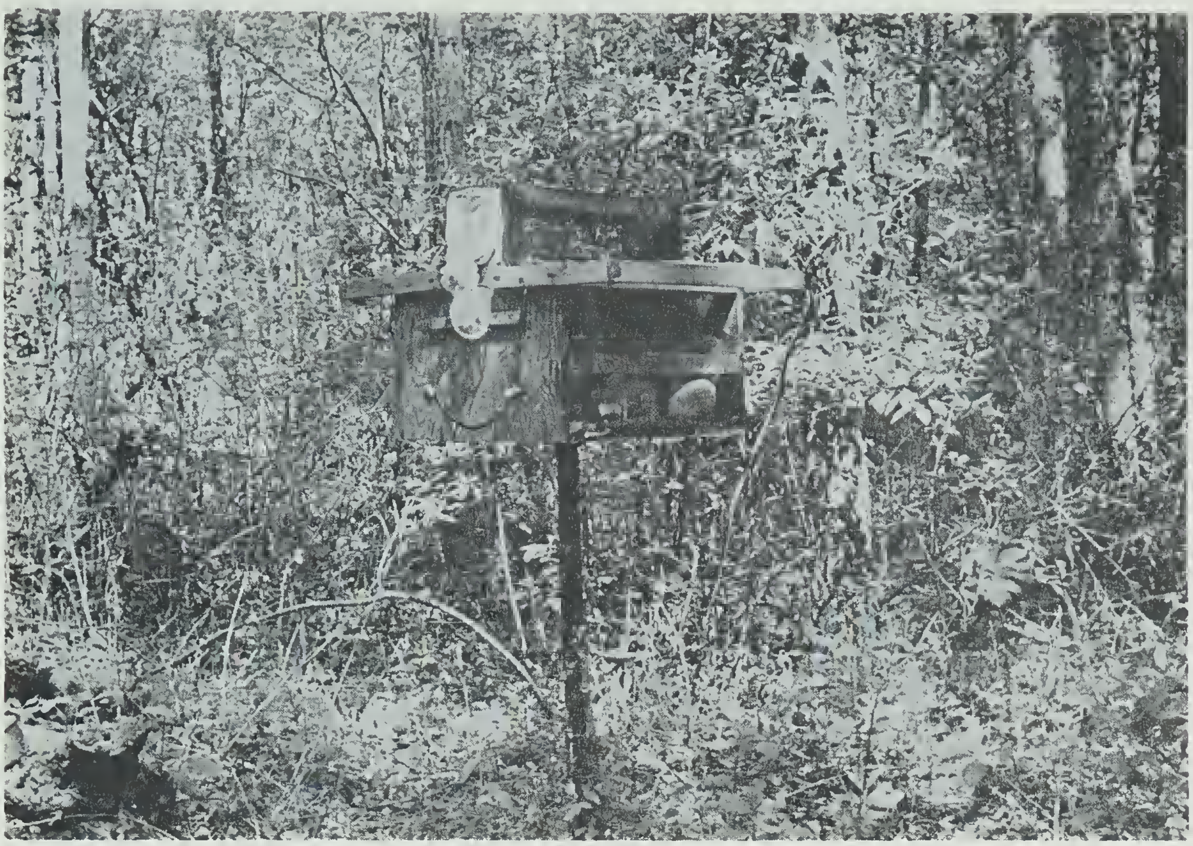


FIG. 13 Rat bait trap I

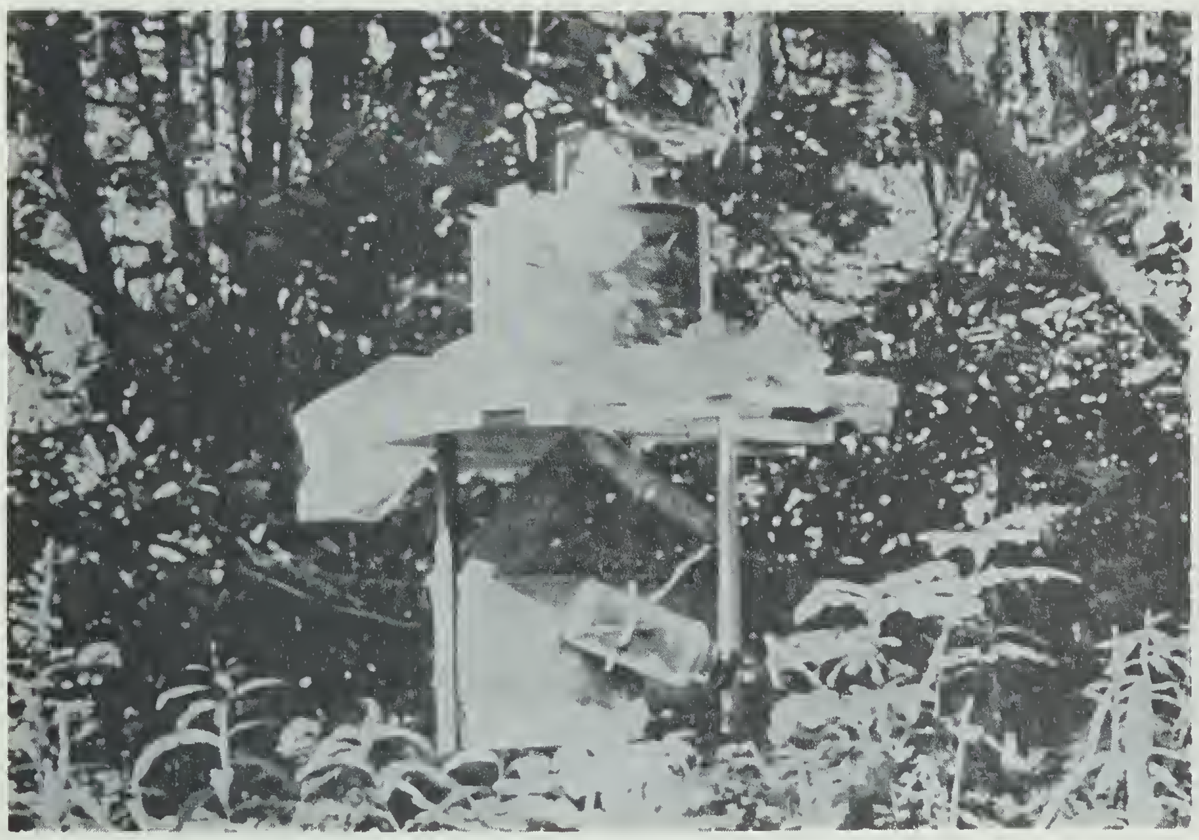


FIG. 14 Rat bait trap II

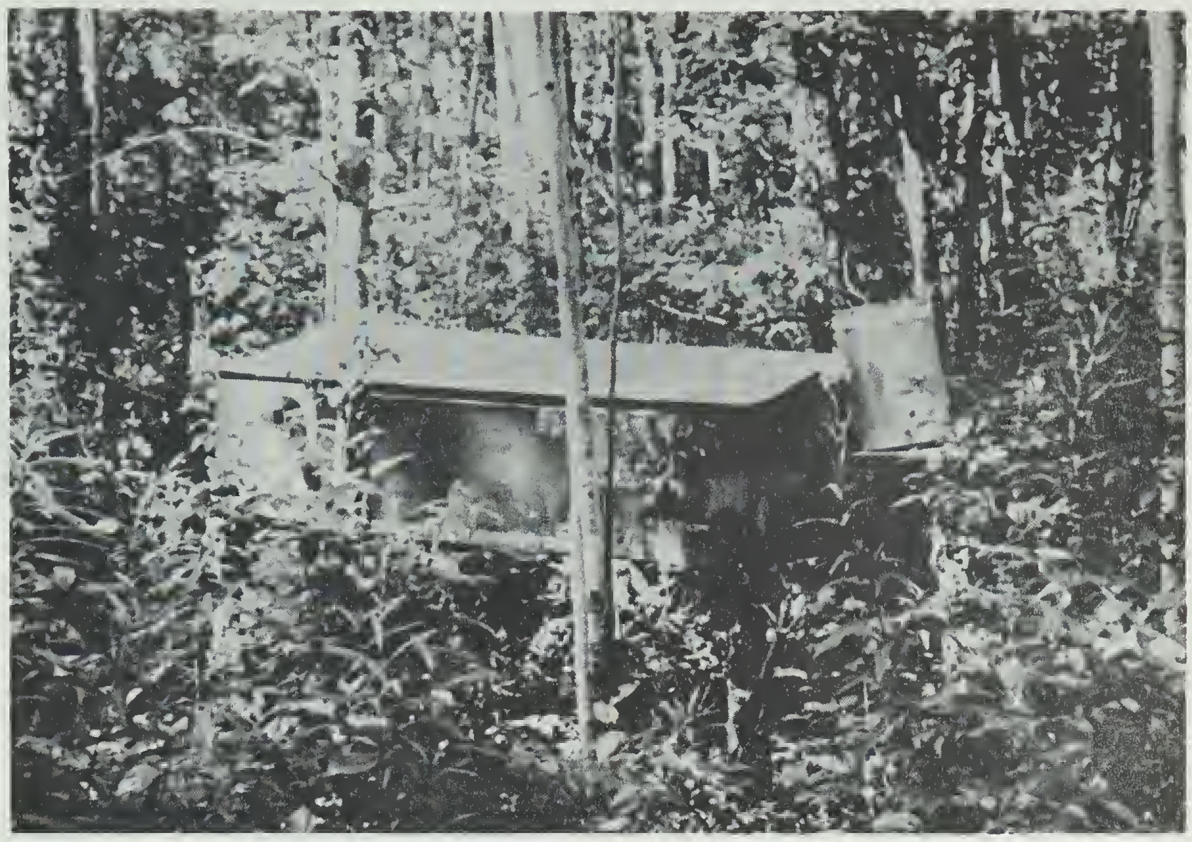


FIG. 15 Chicken bait trap I

FIG. 16 Catching cages of chicken bait trap II

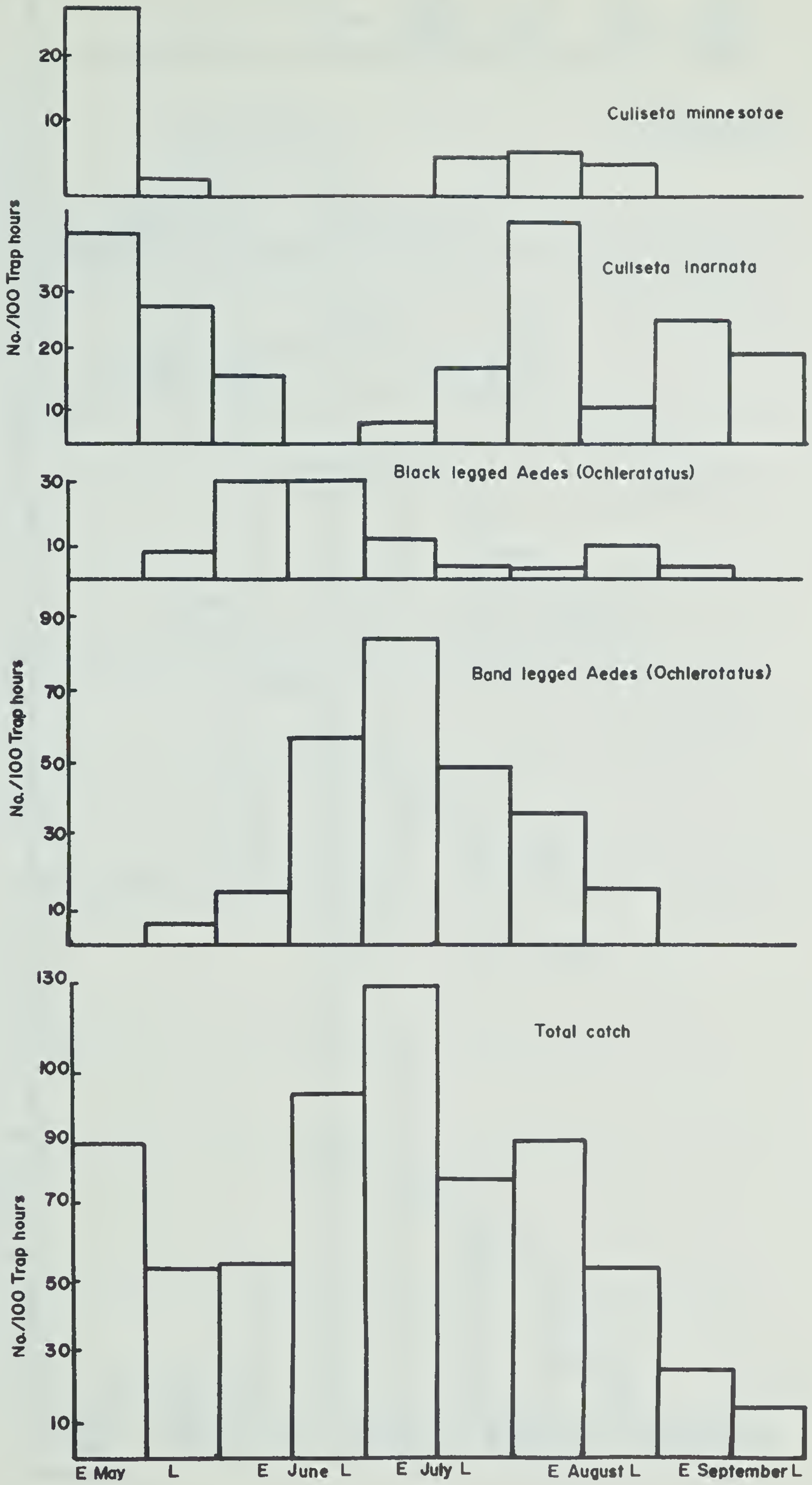
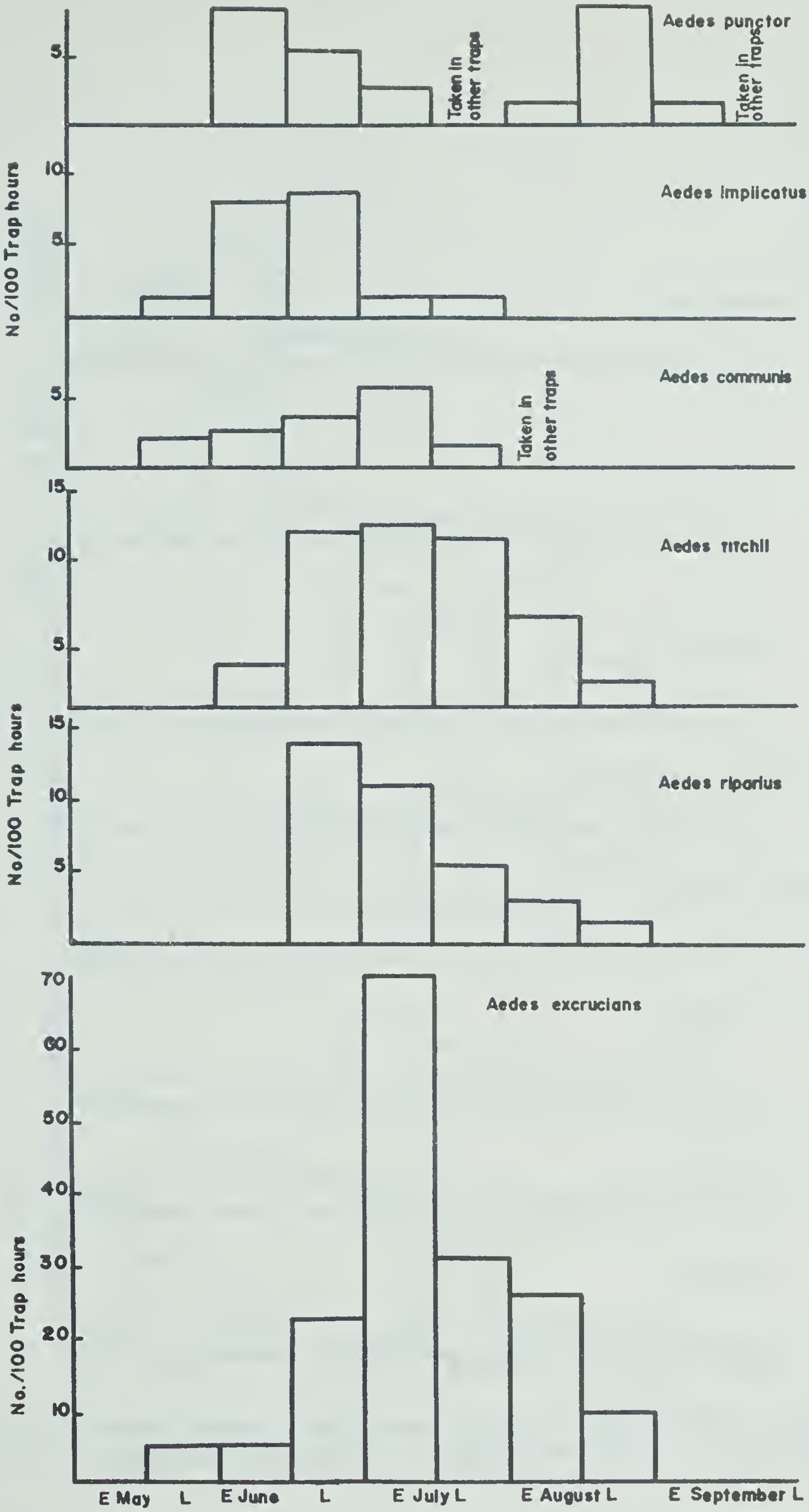


Fig. 17 Seasonal changes in the numbers of mosquitoes caught per 100 trap hours, in Malaise traps, at George Lake. May to September 1966.
E = early L = late



17. continued

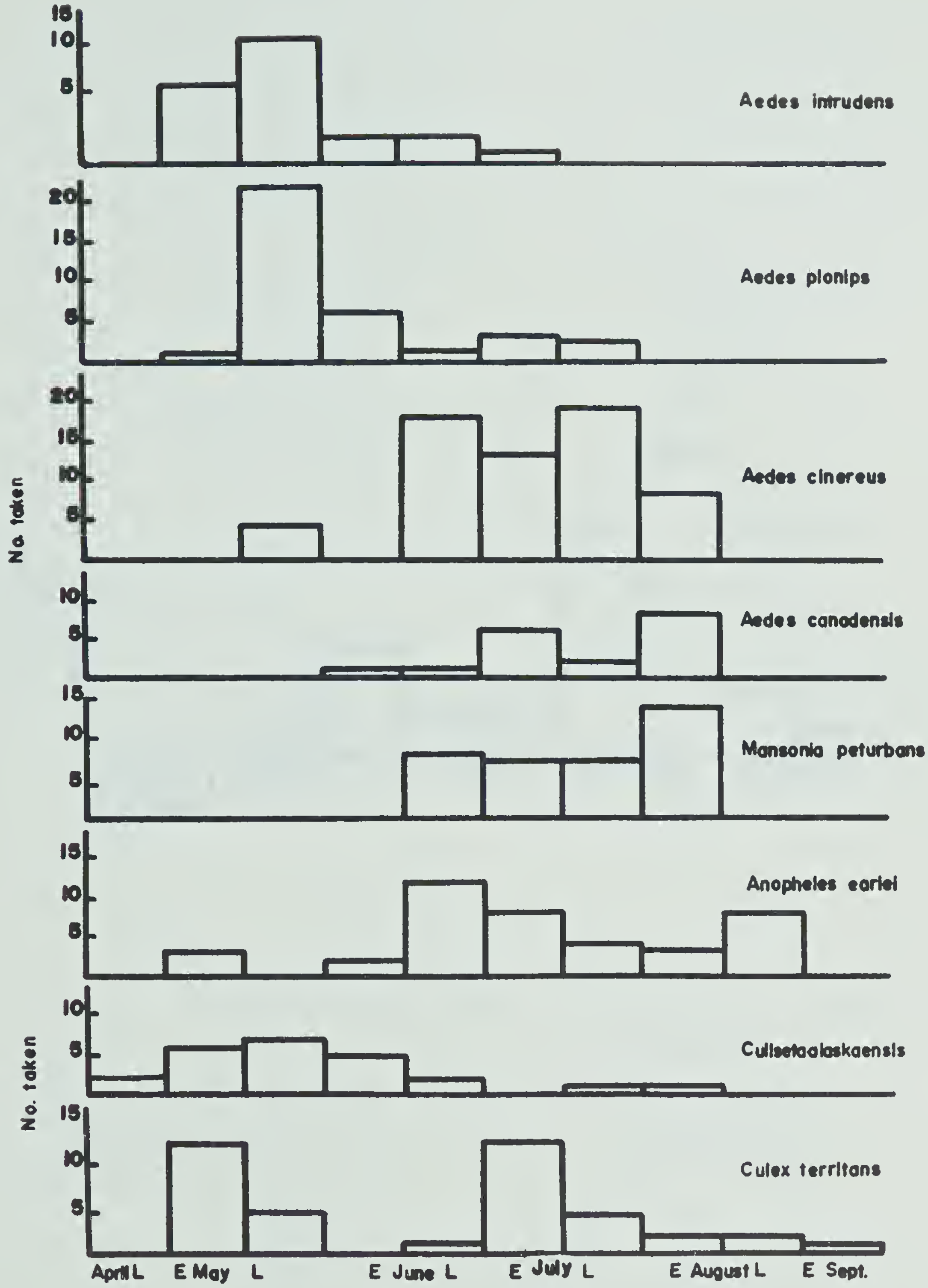
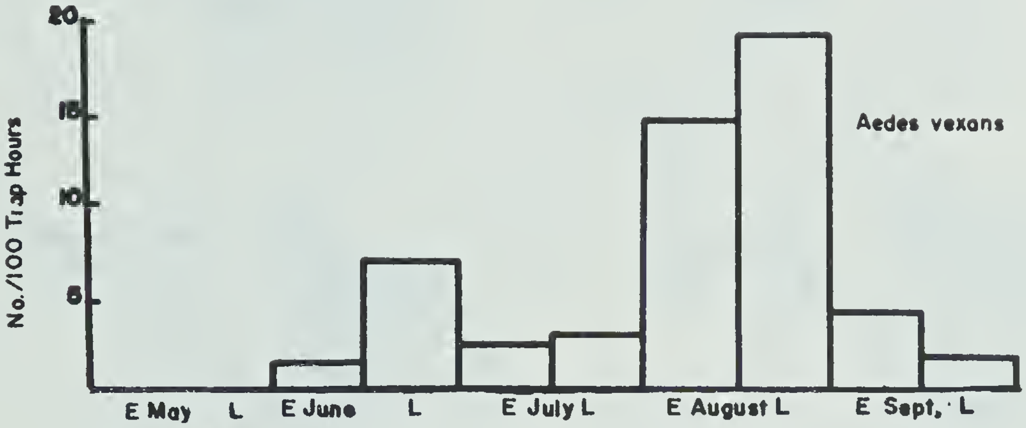


Fig. 18. Seasonal changes in the numbers of some of the less common mosquito species taken by all methods at George Lake, 21 April to 29 September 1966.



17. continued

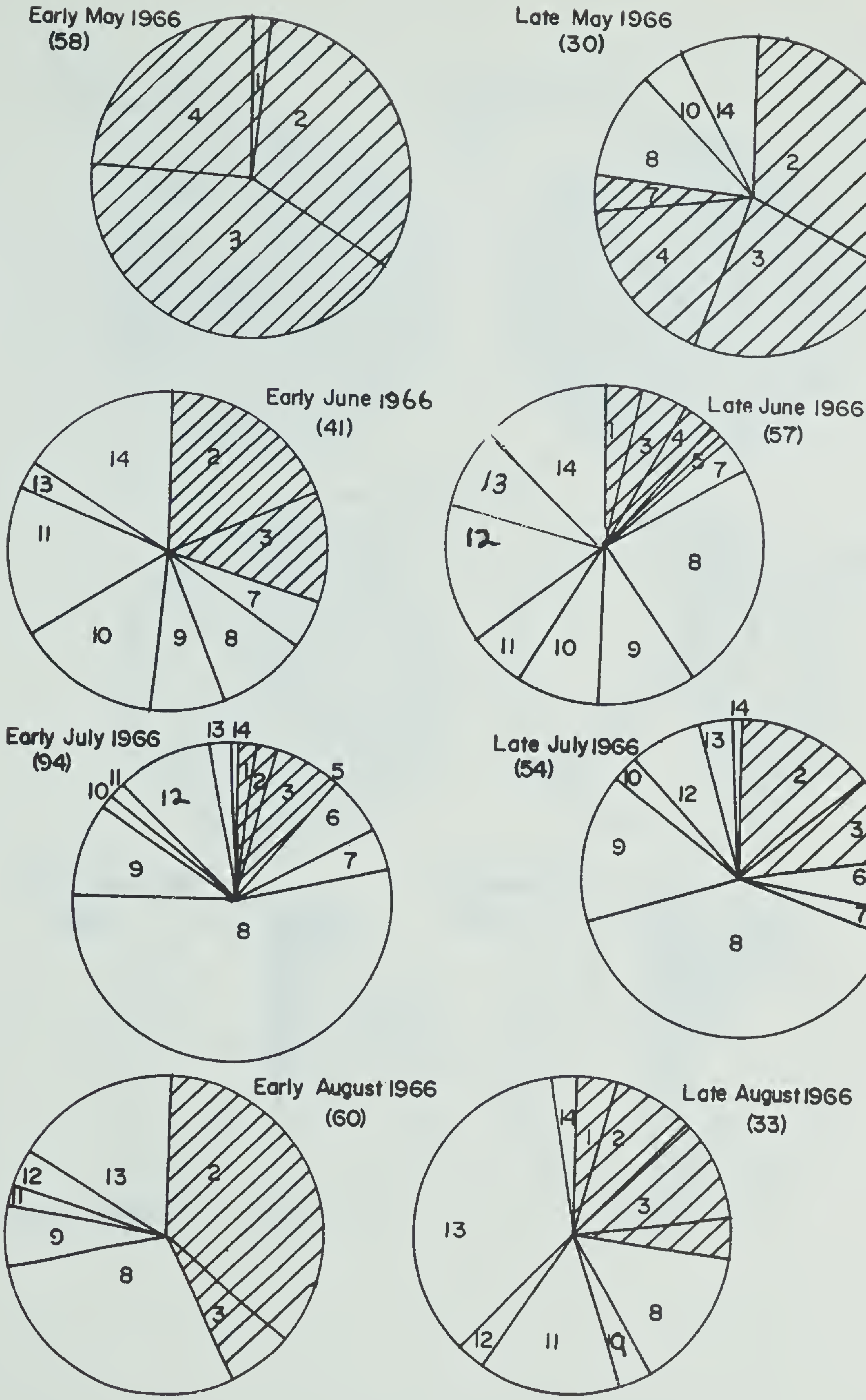


Fig. 19 Seasonal changes in relative abundance of mosquito species at George Lake. May to September 1966.
Numbers as in table 5. Number in brackets = no. caught.
Shaded area = genera other than Aedes

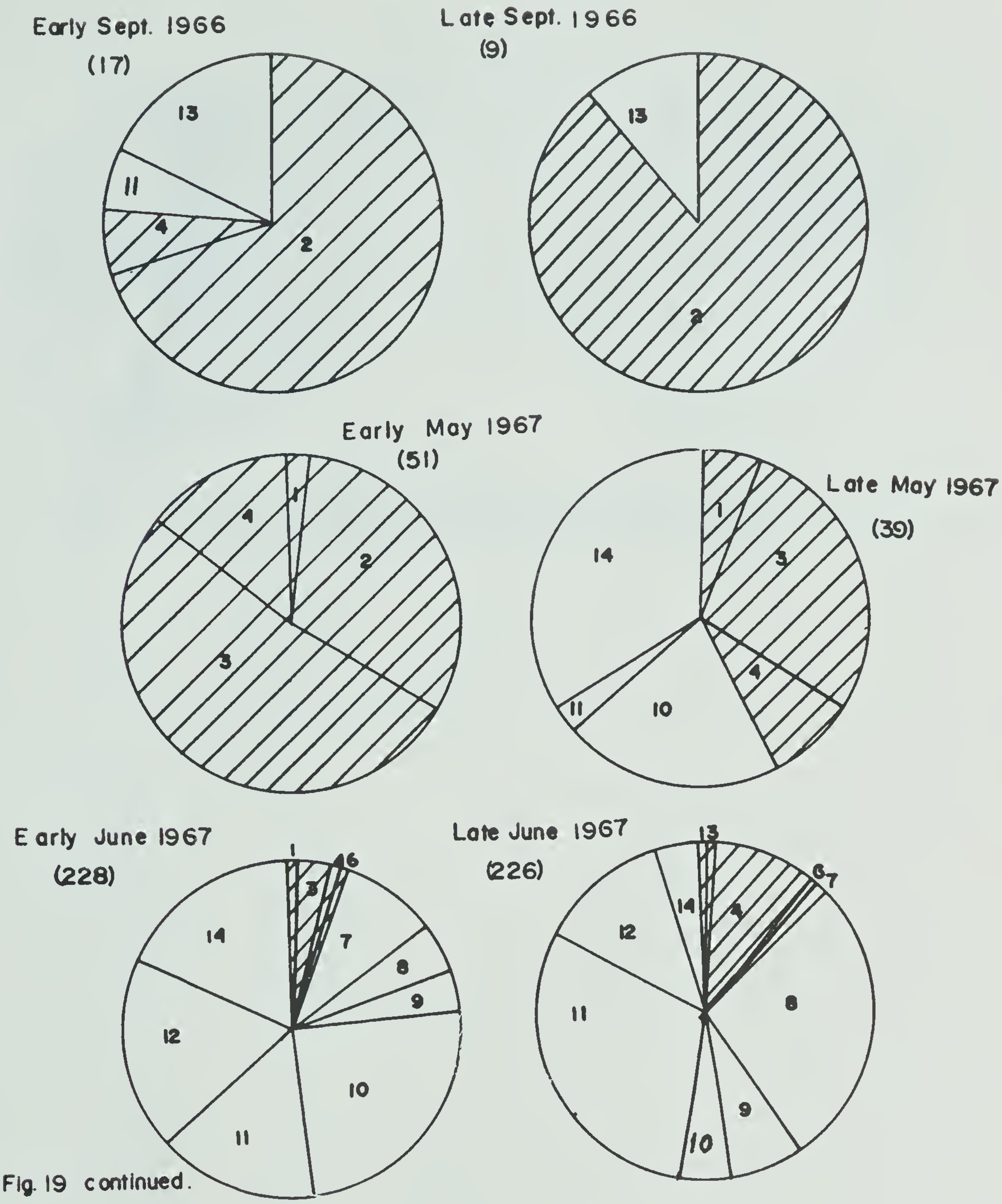


Fig. 19 continued.

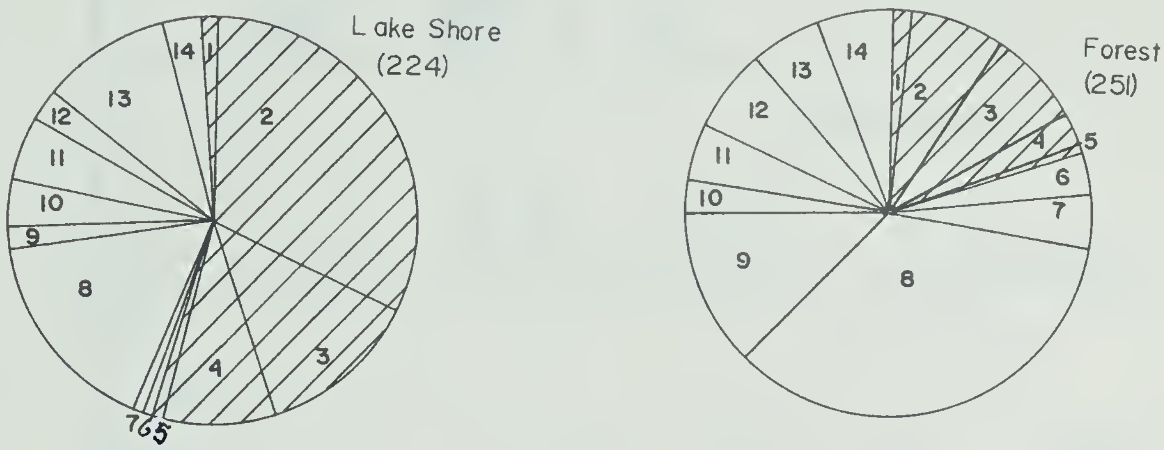


Fig. 20. Relative abundance of mosquito species in Malaise traps at the lake shore and in the forest at George Lake in 1966.

Fig. 21 Seasonal changes in the parity rate of adult female mosquitoes at George Lake. June to August 1966. Shaded area = no. nullipars

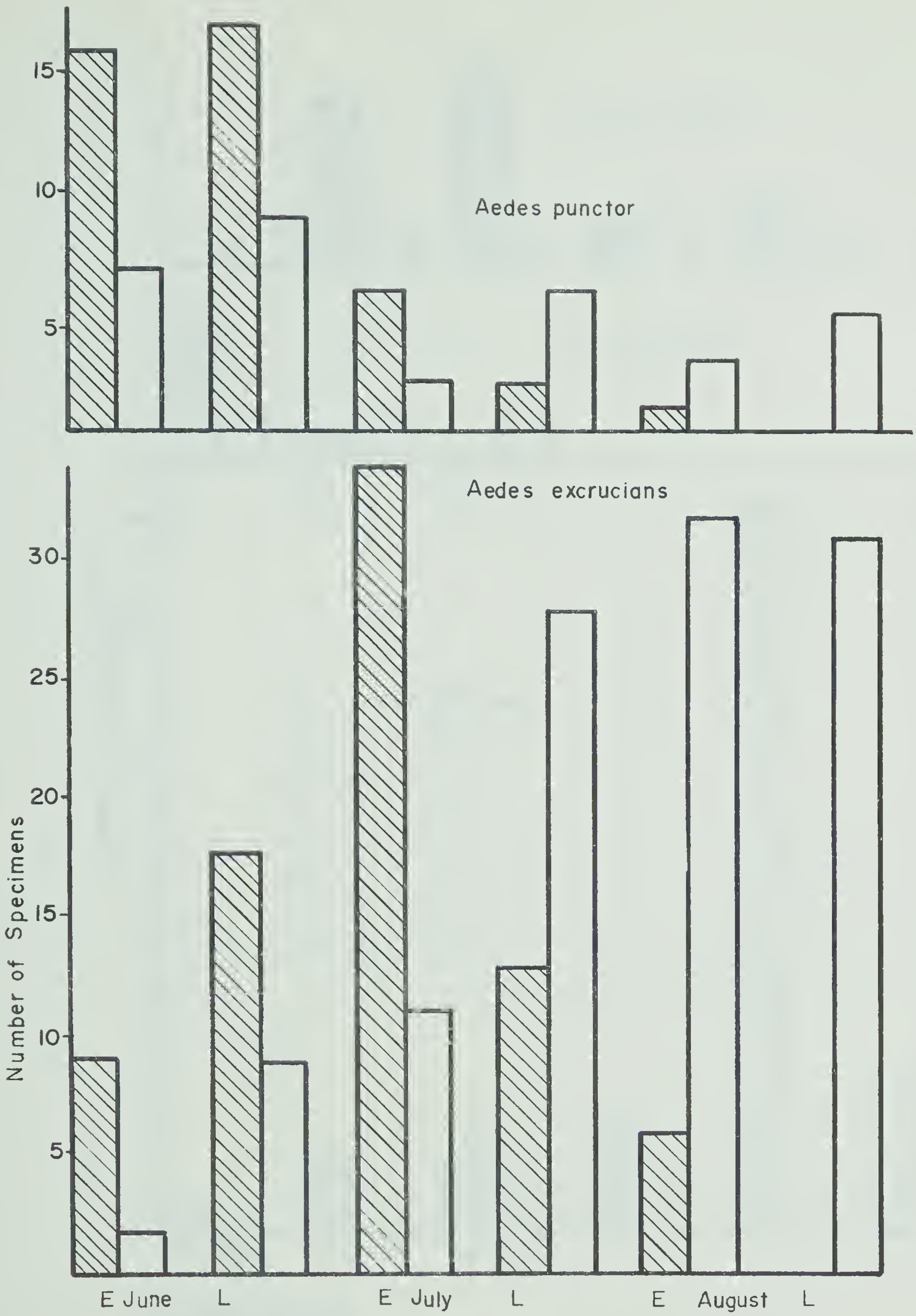


Fig. 21 continued

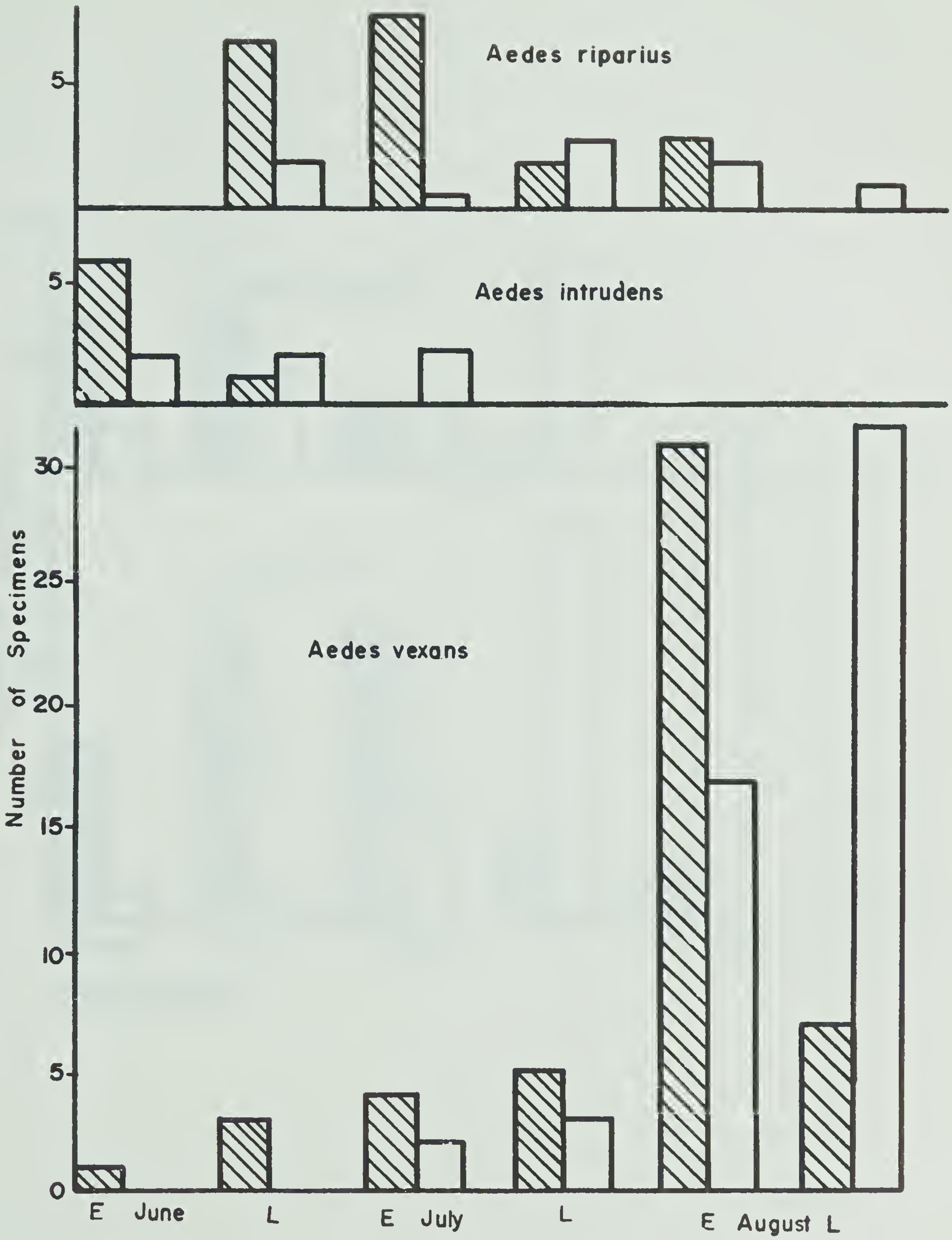


Fig. 21 continued

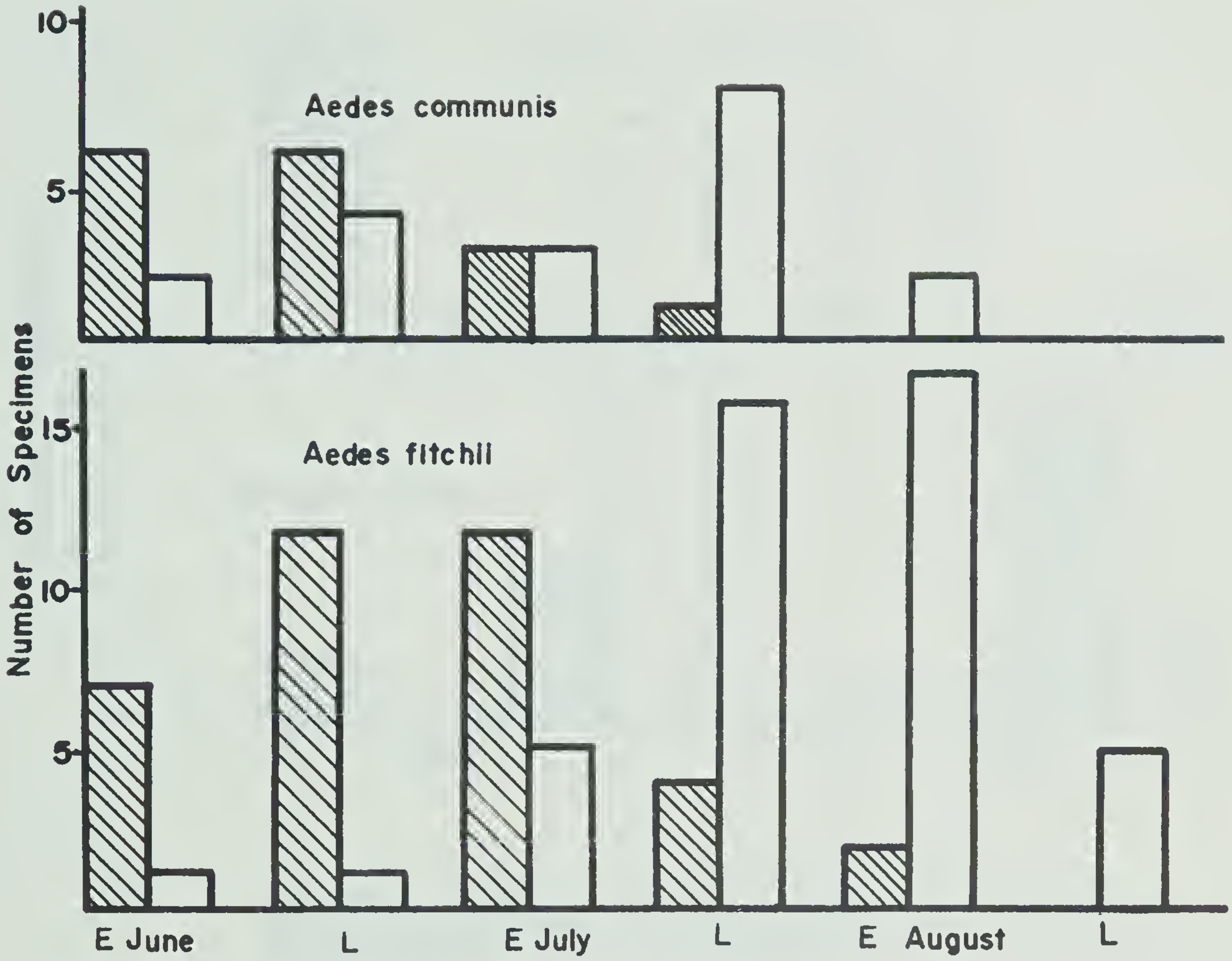


Fig. 21 continued

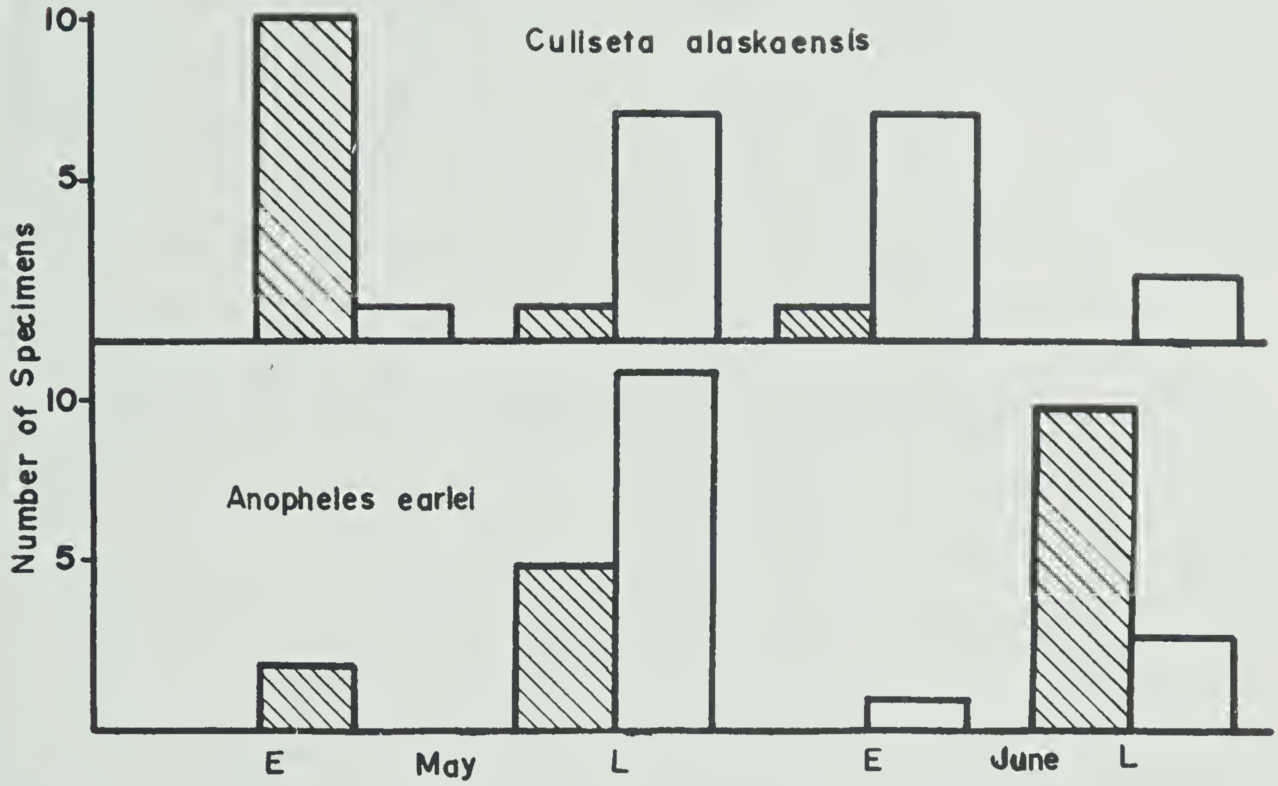


Fig. 22 Changes in parity rate in adult females of *Culiseta alaskaensis* and *Anopheles earlei* during the spring and early summer of 1967 at George Lake.

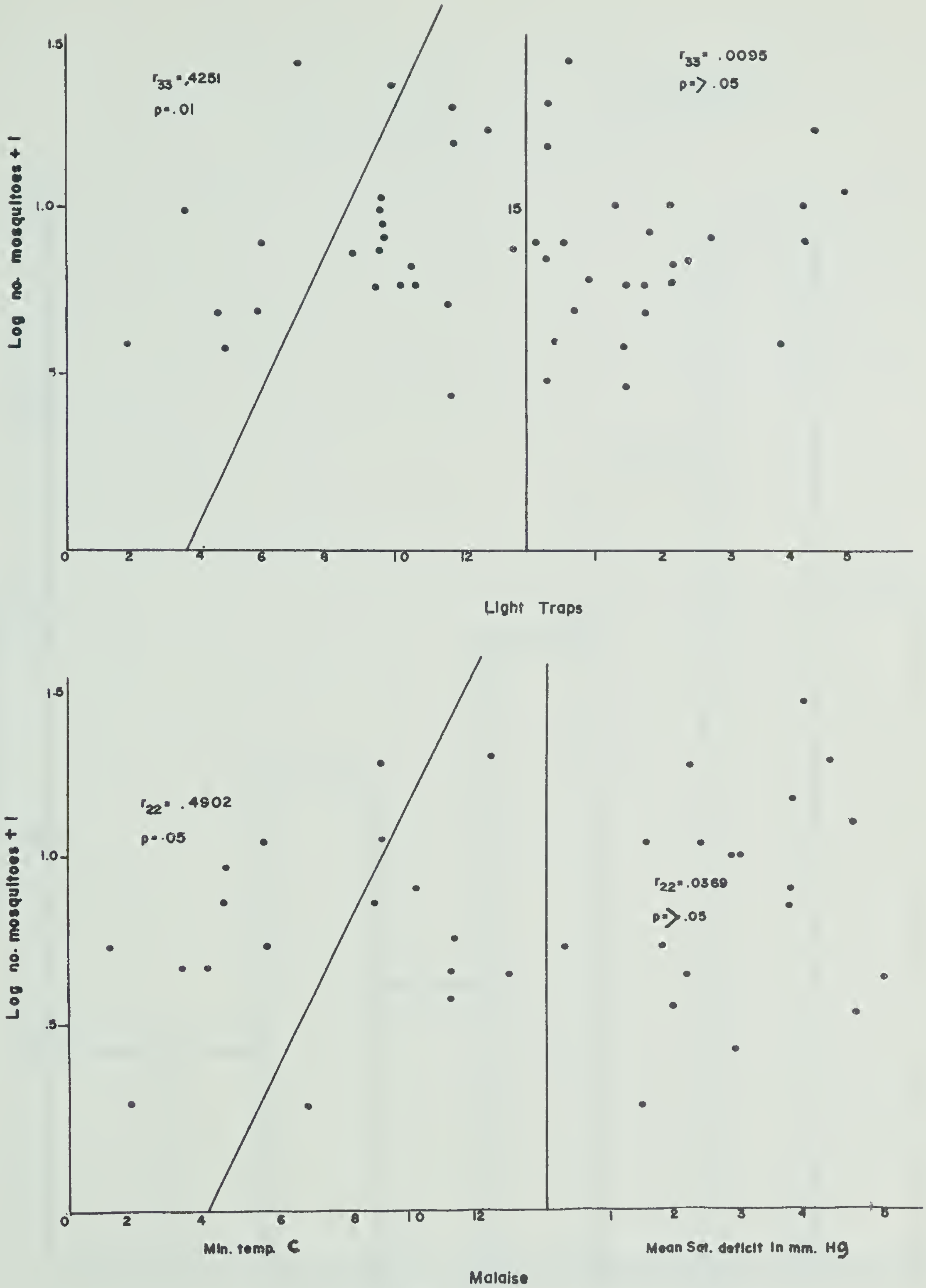


Fig. 23. Relationship between Malaise trap and light trap capture of mosquitoes and minimum nightly temperatures and mean nightly saturation deficit at George Lake, 1 June to 1 September 1966.

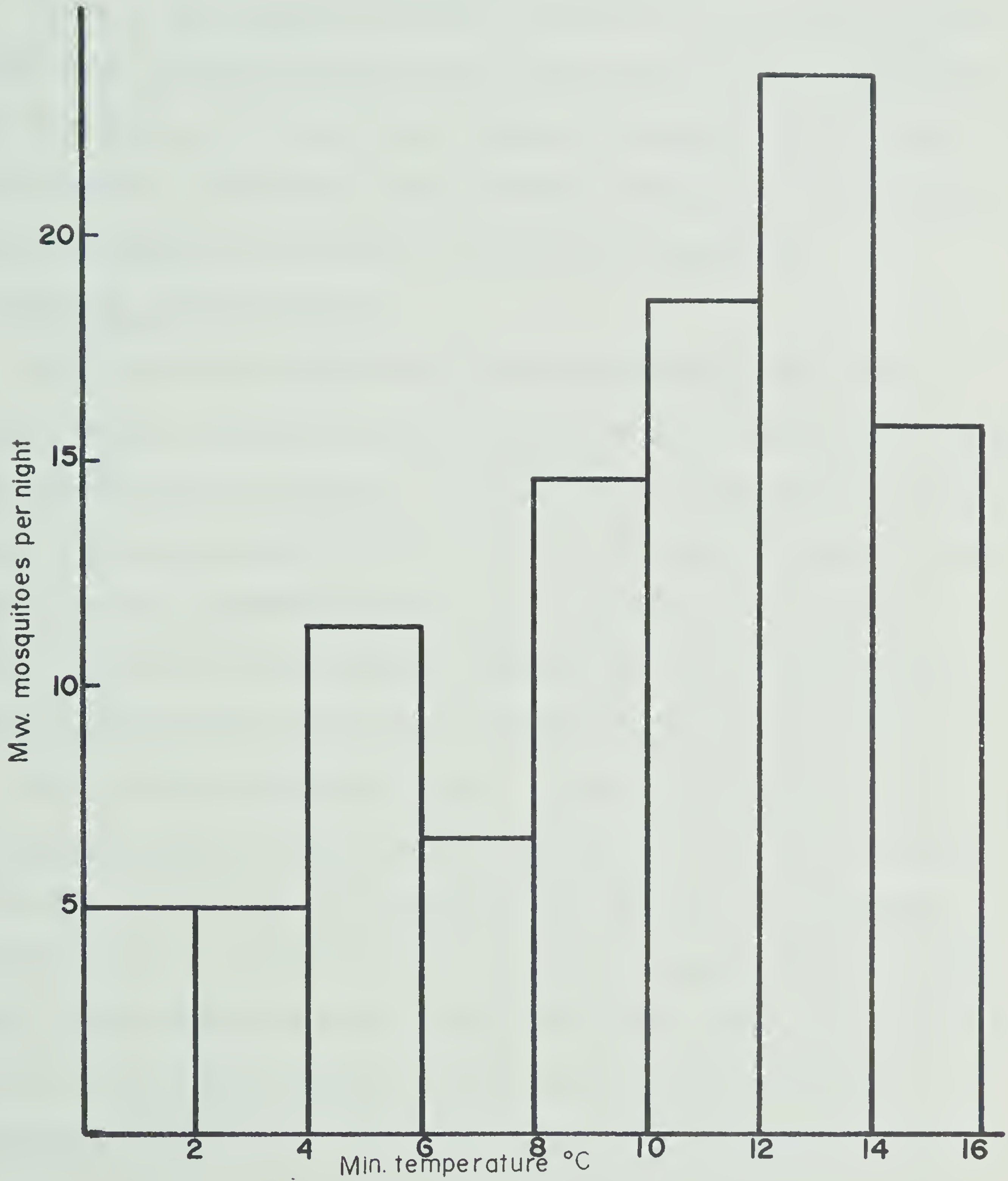


Fig. 24. Effects of minimum nightly temperature on light trapcaptures of mosquitoes at George Lake, 1 June to 1 September 1966.

3. A COMPARISON OF SAMPLING METHODS FOR ADULT FEMALE MOSQUITO POPULATIONS

Seven of the methods described in section 1.2.2., Malaise traps, light traps, visual attraction trap, rotary trap, rat bait, human bait and collections in a trailer were compared both quantitatively and qualitatively. Two methods-human bait and collections in the trailer-were not standardized enough for quantitative comparison.

3.0 Note on statistics used.

The statistical analysis of the data obtained in this study presented certain difficulties, since the nature of the study did not allow the randomization of catches. All traps had to be operated in the same place and technical difficulties as well as the nature of some of the traps prevented simultaneous operation. Therefore the statistical tests applied are not all strictly applicable to the data obtained, though I believe they assist in the interpretation of the results.

Quantitative comparison of the trap types was obtained by converting the catch into catch per 100 trap hours to standardize and to allow for the fact that the different traps were run for different lengths of time. An analysis of variance and Duncan's (1955) multiple range test were applied to the results obtained in 1966. This test is not strictly applicable but does help to confirm conclusions reached by other methods. An index of trap "effectiveness" was obtained by dividing the catch per 100 trap hours in the trap or trap type under consideration by the catch per 100 trap hours in the combined Malaise traps over the same period. The Malaise traps were

chosen as standards as they appear to be passive and to have no attraction for mosquitoes. The combined Malaise traps were used in an attempt to minimize the effects of trap position. This "index of effectiveness" permits a ranking of traps and trap types in order of effectiveness.

A modified geometric mean was used for studying the effects of the addition of carbon dioxide to Malaise traps and the effects of environment on Malaise and light traps. This modification was proposed by Williams (1937) and designated the Williams mean, M_w by Haddow (1960). It is obtained by the expression $M_w = \text{antilog}\left(\frac{(\Sigma \log(x + 1))}{N}\right) -1$ where x is the value of each sample and N the number of samples. The addition of one to each sample value allows the inclusion of zero catches which cannot be included in a normal geometric mean. Williams (l.c.) has shown that where there is a large variation in the size of samples or one sample is very different from the others, this mean gives a better measure of central tendency than the arithmetic mean.

The χ^2 test was used in the qualitative comparison of the trap types.

3.1. Relative effectiveness - catch per unit time

Table 9 shows the relative effectiveness of the traps in 1966 and 1967 and Table 10, the effectiveness in June of 1966 and 1967. Table 11 shows the catch per 1000 trap hours of the five most abundant species and Culex territans which is believed to feed on cold blooded vertebrates and so differs from the other species caught which are believed to feed mainly on warm blooded vertebrates.

The results in May and June 1967 are similar to those in 1966

Table 9 The numbers of adult female mosquitoes taken per 100 trap hours in different traps at George Lake 1966 and 1967.

Trap	1966 (June July August)			
	No. Caught	No. trap hours	No. mosq/ 100 hrs.	Index of*** Effectiveness
Malaise I	146	2099.5	7.0	0.8
Malaise II	214	2048	10.7	1.2
Total Malaise	365	4147	8.8	1.0
Mal I+CO_2*	589	104.5	559.4	67.6
Mal II+CO_2*	264	98	269.9	30.7
Total Mal+CO_2*	853	207.5	411.1	51.1 (35.1)* **
Light I	141	266.5	52.9	6.0
Light II	48	267	18.0	2.0
Total Light	184	533.5	35.4	4.0
Vis. attr.	93	261.2	35.6	4.0
Rotary	116	260	44.6	5.1
Rat bait I	154	711.5	21.6	2.5
Rat bait II*	19	191	9.9	1.1
Total rat bait	172	902.5	19.1	2.2
Chick. bait I*	42	744	5.6	0.6

Table 9 continued.

Trap	1967 (May June)			
	No. Caught	No. trap hours	No. mosq/ 100 hrs.	Index of*** Effectiveness
Malaise I	124	977	12.7	.53
Malaise II	344	977	35.3	1.47
Total Malaise	468	1954	24.0	1.0
Mal I+CO_2	1080	112	964.2	40.26
Mal II+CO_2	5640	112	5035.7	210.2
Total Mal+CO_2	6720	114	3000.0	125.3 (97.4)**
Light I	93	120	77.5	3.4
Light II	37	120	30.8	1.3
Total Light	130	240	54.2	2.3
Vis. attr.	56	49	114.3	4.8
Rotary	114	49	232.6	9.7
Rat bait I	129	262	49.2	2.1
Rat bait II	-	-	-	-
Total rat bait	-	-	-	-
Chick. bait I	-	-	-	-

* August only

** Adjusted using Malaise trap figures per equivalent nights

*** The 'Index of Effectiveness' is the no. of mosquitoes per 100 trap hours taken in trap, divided by the no. of mosquitoes per 100 trap hours in the combined Malaise traps.

Table 10 Comparison of mosquito captures per 100 trap hours in June 1966 and June 1967 at George Lake.

Trap	1966	1967	Index of Effectiveness 1966	Index of Effectiveness 1967	Comparative Increase in catch 1967/66
Malaise I	5.14 (37)	16.8 (108)	.76	.49	3.26
Malaise II	9.45 (59)	51.3 (329)	1.32	1.50	5.43
Tot. Malaise	7.13 (96)	34.1 (437)	1.0	1.0	4.78
Light I	45.83 (44)	135.9 (87)	6.4	3.98	2.96
Light II	15.0 (12)	51.6 (33)	2.10	1.51	3.44
Tot. Light	35.0 (56)	93.8 (120)	4.91	2.75	2.68
Vis. attr.	41.30 (46)	137.5 (55)	5.79	4.03	3.32
Rotary	31.40 (36)	285.0 (114)	4.40	8.36	9.08
Rat Bait I	25.4 (97)	79.2 (122)	3.56	2.32	3.12

Fig. in brackets = no. mosquito caught. Av. increase 4.30

Table 11 Numbers of adult females of selected species of mosquito caught per 1000 trap hours and actual numbers caught in different trap types at George Lake from 1 June to 1 September 1966.

Trap	Culiseta inornata	Culex territans	Aedes excrucians	A. fitchii	A. punctor	A. vexans
Malaise I	20 (72)	6 (20)	10 (37)	1 (3)	3 (11)	7 (23)
Malaise II	6 (18)	2 (6)	27 (89)	10 (32)	3 (11)	4 (14)
Tot. Malaise	13 (90)	4 (26)	19 (126)	5 (35)	3 (22)	6 (37)
Mal. I+CO_2	100 (11)	9 (1)	632 (69)	289 (36)	421 (46)	3352 (336)
Mal. II+CO_2	10 (1)	10 (1)	1165 (114)	405 (40)	112 (11)	785 (77)
Tot. Mal+CO_2	58 (12)	10 (2)	1002 (182)	365 (76)	275 (57)	2135 (413)
Light I	264 (70)	8 (2)	30 (8)	49 (13)	8 (2)	23 (6)
Light II	4 (9)	0 (0)	38 (10)	8 (2)	8 (2)	22 (6)
Tot. Light	148 (79)	4 (2)	34 (18)	28 (15)	8 (4)	22 (12)
Vis. Attr.	0 (0)	38 (10)	70 (18)	27 (7)	54 (14)	8 (2)
Rotary	12 (3)	15 (4)	39 (10)	31 (8)	50 (13)	31 (8)
Rat Bait I	1 (1)	0 (0)	59 (42)	21 (15)	31 (22)	7 (5)

except that light traps caught less than either the visual attraction or the rotary traps and the catch per 100 trap hour in all traps averaged four times larger than in 1966.

Perhaps the most interesting result was the high catch in the rotary trap which is generally believed to have no attractive influence and to take a random sample of flying insects (Stage and Chamberlin 1945; Love and Smith 1957; Juillet 1963; Southwood 1966). This trap had an index of effectiveness of 5.1 in 1966 and 9.7 in 1967 and was well within the range of traps with an attractive influence, namely light, bait, and visual attraction traps. This indicates that the rotary trap does in fact exert some attractive influence on mosquitoes. It was impossible to observe the approach of mosquitoes to a trap of this size so that the nature of this influence could not be elucidated. It is well known that many biting Diptera including mosquitoes (Clement 1963) are attracted to moving objects. Tabanids and tsetse flies (Glossina sp.) are attracted to moving motor vehicles (Duke 1955; Glascow 1963). The stimulus of a rotary trap may be similar to that of a moving vehicle.

Though the light traps caught nearly three times as many mosquitoes in June 1967 as in June 1966, their relative effectiveness was nearly halved. This is probably due to the absence of Culiseta inornata in 1967 as this species formed a large proportion of the 1966 catch.

Apart from the rotary and light traps the "indices of effectiveness" for the two years are very similar. This indicates that the relative effectiveness of a trap does not change much with population

size; but it may be changed considerably if the species composition changes.

The number of mosquitoes per unit volume of air filtered in June 1967 was calculated for the rotary, visual attraction, and light traps. Only the volume of air flowing through the trap was used; no estimate of "area of influence" was made. This gives an estimate of the actual efficiency of these traps. The rotary trap captured 2.4 mosquitoes, the visual attraction trap 0.3 and the light traps 1.3 mosquitoes per 10,000 cubic feet of air. If it is assumed that rotary traps have no attraction to mosquitoes but capture only those which come within range, then the efficiency of rotary and Malaise traps should be approximately the same. I calculated the air flow needed to give a catch of 34.1 mosquitoes per 100 trap hours (the figure in Malaise traps) if the efficiency in Malaise traps is the same as that of the rotary trap. This was 23.5 cubic feet per minute, which means that the average wind speed through these traps would have been 0.9 feet per minute. That is, these traps would have to have been standing in virtually still air during June 1967; since this was not so, I infer that the efficiency of the Malaise traps was below that of the rotary trap.

The high actual efficiency of the rotary trap, above both light and visual attraction traps, is additional evidence that this type of trap does provide an attractive stimulus for mosquitoes.

The results of analysis of variance and Duncan's (1955) Multiple range test (appendix) supported these findings.

3.2. Proportion of males

Comparatively few males were taken and relatively little attention was paid to them as they formed only about 1% of the total catch in 1966 and 1967. Table 12 shows the proportion of males taken in 1966 and in 1967.

In both years light traps took the largest proportion of males, but the statistical significance of this is doubtful. The position of the trap was important, light trap II took a much greater proportion in both years than light trap I. Light traps are known to take a larger proportion of the males of some insects than are in the population (Southwood 1966) and to take large numbers of male mosquitoes (Barr 1958). Belton and Galloway (1965) found 50% of light trap captures of nearly 6000 mosquitoes were males at Belleville in Ontario. Breeland and Pickard (1965), however, found 22% in Malaise trap captures were males but only 12% in light traps.

3.3. Species composition

3.3.1. Diversity - The index of diversity α was introduced by Fisher et al. (1943) as a measure of the diversity of a population. It is obtained from the expression $S = \alpha \log_e(1+N/\alpha)$ where S is the number of species and N the number of individuals. An approximation, adequate for most needs, can be obtained from nomograms in Williams (1964) and Southwood (1966). This index is dependent on the size of the sample as well as its diversity but is useful for comparing traps operated the same period and has been successfully used to compare methods of catching Heteroptera by Southwood (1960).

Table 12 Proportions of male mosquitoes in traps at George Lake, 1966 and 1967.

Trap	1966 (1st June - 1st Sept.) No. ♂♂	Total catch	♂ : ♂ + ♀	1967 (15 May - 30 June) No. ♂♂	Total catch	♂ : ♂ + ♀
Malaise I	12	158	0.076	9	133	0.068
Malaise II	8	228	0.035	21	365	0.058
Tot. Malaise	20	386	0.052	30	498	0.060
Mal. I CO_2	2	512	0.0039*	5	1085	0.00461
Mal. II CO_2	0	130	0.00*	5	5645	0.000886
Tot. Mal. CO_2	2	642	0.0031*	10	6730	0.00148
Light I	10	149	0.067	6	99	0.061
Light II	35	78	0.45	5	42	0.12
Tot. Light	45	227	0.20	11	141	0.078
Vis. attr.	13	106	0.123	2	58	.034
Rotary	4	120	0.033	1	114	.0088
Total	84	1481	.0567	54	7541	0.0072

X^2_2 1966 - 33.033 P = .005 (Light against rest)

X^2_2 1967 - 1.457 P = .5 (Light against rest)

* August only

The indices of diversity for the trap types in 1966 are shown in Table 13. There were no significant differences between trap types, which indicates that the smaller catches were due to lower effectiveness rather than to the unavailability of certain species.

3.3.2. Proportions of different species

The proportions of the major species in the catches of the different trap types are shown in Table 13. Table 14 shows the proportions in paired traps.

The low catch of Culiseta inornata in the rotary trap and the absence of this species from the visual attraction trap in 1966 is hard to explain since this species formed 27% of the catch in the nearby Malaise I.

The animal bait traps showed great similarity. The rat and chicken bait traps did not differ significantly while the human bait and rat bait traps differed only at the 5% level. Aedes canadensis formed over 20% of the catches in chicken bait traps but was scarce in other traps and A.cinereus was most abundant in human bait catches.

3.3.3. Discussion

The results of Breeland and Pickard (1965) are of interest. They found 52% of Malaise trap captures were Aedes compared to 54% in light traps and 50% in biting catches. Forty seven percent of the Aedes in their Malaise traps and 52% in their light traps were A.vexans indicating that the preponderance of the species in light traps is often more due to its preponderance in the population rather than to any specific attraction to light, though this species is often stated to

Table 13 Comparison of the percentages of the more numerous mosquito species in the traps 1st June to 1st September 1966 at George Lake.

Species	Tot. Mal.	Tot. Light	Vis. Attr.	Rotary	Rat Bait I	Chick. Bait	Human Bait	Trailer
Anopheles earlei	1.4	9.9	8	6				0.9
Culiseta inornata	11.1	43.4		4	0.8		0.8	0.9
Other *Culiseta*	4.7	1.6					0.8	
Culex territans	1.7	1.1	13	5				
Mansonia perturbans	0.6	2.8		1	3.9		1.7	
Aedes cinereus	3.0	2.2	3	1	0.8		14.2	
A.communis	2.8	0.6	3	7	9.4	12	5.0	8.9
A.excrucians	34.1	9.9	24	12	33.1	42	29.2	17.8
A.fitchii	9.7	8.2	9	10	7.9		18.3	7.1
A.implicatus	3.9	1.1	4	6	3.2	4	4.2	2.7
A.punctor	5.8	2.2	19	16	17.3	8	5.8	29.6
A.riparius	5.8	3.8	3	6	6.3	4	4.2	0.9
A.vexans	9.2	6.6	3	10	3.9	4	5.0	1.8

Table 13 continued.

Species	Tot. Mal.	Tot. Light	Vis. Attr.	Rotary	Rat Bait I	Chick. Bait	Human Bait	Trailer
Other *Aedes*	6.4	6.7	12	17	13.4	25	10.8	29.4
Total *Aedes*	82.9	40.7	79	84	94.6	100	96.7	98.3
Total No. identified	361	182	75	83	127	24	120	111
No. Species	24	22	15	18	18	7	17	16
Index of Diversity α	$6\pm.6$	$.6\pm.9$	$5\pm.1.0$	6 ± 1.0	$5\pm.8$	3 ± 1.5	6 ± 1.2	5 ± 1.0

X^2_{13} Mal Vs. lt. = 75.664 P =<.001

X^2_8 Mal. Vs. vis. attr. = 38.204 P =<.001

X^2_9 Mal. Vs. Human bait 108.127 P =<.001

X^2_9 Mal. Vs. rotary 44.99 P =<.001

X^2_6 Mal. Vs. trailer = 95.857 P =<.001

X^2_5 Mal. Vs. rat bait = 22.964 P =<.001

X^2 Human bait Vs. rat bait 14.283 P =<.05

Table 14 Comparison of the proportions of mosquito species taken in paired traps 1st June - 1st September 1966 at George Lake.

Species	Mal. I	Mal. II	Mal.+CO_2* I	Mal.+CO_2* II	Light I	Light II
Anopheles earlei	1.4	1.4	.012	0	9.4	12
Culiseta inornata	26.7	0.5	1.7	0.4	50.3	21
Other Culiseta	8.2	2.3	0.5	0	2.2	
Culex territans	1.4	1.9	0.2	0.4	1.4	
Mansonia perturbans	0.7	0.5	2.5	0.7	2.2	5
Aedes cinereus	1.4	4.2	2.0	0.4	0.7	7
Aedes communis	0.7	4.2	0.6	0	0.7	
A.excrucians	23.3	41.5	14.8	43.2	5.6	23
A.fitchii	2.1	14.9	5.6	15.1	4.4	5
A.implicatus	5.5	2.8	0.2	0	0.7	2
A.punctor	6.9	5.1	7.6	4.2	1.4	5
A.riparius	3.4	7.4	3.6	2.6	5.1	
A.vexans	13.0	6.5	57.6	29.2	4.3	4
Other Aedes	5.5	7.0	4.7	3.8	6.5	7
Total Aedes	61.5	96.0	97.4	98.6	33.8	63
Total ident.	146	215	636	264	139	43
No. species	21	19	19	13	21	11

Table 14 continued.

* July and August only

X^2_{12}	Malaise	170.65	$P = < .001$
X^2_6	Mal+CO_2	15.11	$P = < .01$
X^2_6	Light	26.23	$P = < .01$

be greatly attracted to light (Huffacker and Bach 1943; Love and Smith 1957). Although Love and Smith found a high "index of attractivity" to light for this species, the proportion of A.vexans was actually higher in their sweep nets than in their light traps (53% and 50% respectively). Breeland and Pickard found light traps gave a significantly lower diversity, 3 ± 0.3, than the Malaise traps, 5 ± 0.5 (my calculations). At George Lake only Culiseta inornata and Anopheles earlei were above the numbers expected in light traps if there was no difference between trap type.

Haufe and Burgess (1960) compared a visual attraction trap to a suction trap, which like a Malaise trap presumably takes a random sample of the flying insect population. They found that though a visual attraction trap caught ten times as many mosquitoes as a suction trap, there was no significant difference between the proportion of band-legged and black-legged Aedes between the two traps. At George Lake the main difference between Malaise I and the visual attraction trap was the low number of Culiseta inornata and the high number of Culex territans in the visual attraction trap and there were no significant differences in the proportions of Aedes species, which indicates that this trap takes a random sample of the mosquitoes which approach it. Haufe and Burgess (l.c.) found this trap caught all mosquitoes approaching to within about 30 inches of it and observations at George Lake support this.

The rotary trap catch was significantly different from the Malaise trap catch but this applies mainly to the catch of Culiseta inornata

which was lower than expected and that of *Aedes punctor* which was higher than expected. In 1967 this species formed 58% of the catch. The evidence shows that this trap exerts an attractive stimulus to mosquitoes and this may be selective for some species, possibly *A.punctor*.

The animal bait traps differ from the others in that their attraction depends on the feeding habits of the adult female mosquitoes. Captures on chickens, rats, and humans differed very little. Differences between human bait and the others were probably due to position.

3.4. Effects of carbon dioxide on the catch in Malaise traps

Rudolfs (1922) suggested that mosquitoes were attracted to carbon dioxide and since then some controversy has arisen over whether this is merely an activating agent (Willis 1947; Laarman 1955) or whether it also has an orienting effect (Reeves 1953), but Clement (1963) states the importance of carbon dioxide as an aid in host finding by mosquitoes has yet to be determined.

Several workers have found that the addition of dry ice (solid carbon dioxide) to light traps greatly increases the catch (Reeves and Hammon 1942; Huffacker 1942; Huffacker and Bach 1943 and Newhouse *et al.* 1966). Carestia and Savage (1967) found that the catch in a C.D.C. miniature light trap was greatly increased by the addition of carbon dioxide from a cylinder and that the catch increased as the rate of flow was increased. Reeves (1953) used carbon dioxide as bait in a stable trap and caught large numbers of *Culex tarsalis* at 26 ml. CO_2 per minute (equivalent to one chicken) and the catch increased as the rate of flow increased. Bellamy and Reeves (1952) designed a portable

trap, from a twenty pound lard can, which used dry ice as bait. Schoeppner and Whitsel (1967) and Gillies and Snow (1967) have published designs for carbon dioxide baited sticky traps for mosquitoes and other biting flies.

Hayes *et al.* (1958) and Dow (1959) have compared carbon dioxide bait with other mosquito attractants and find it compares very favorably as an attractant for adult females and Brown (1951) and Brown *et al.* (1951) have found carbon dioxide an effective attractant in the field.

Table 15 shows the catch of mosquitoes in Malaise + CO_2 traps and in Malaise traps over a period of six nights in 1966 and seven in 1967, the traps were run from 1700 hours to 0900 hours the following morning.

Table 16 shows the proportions of species in the Malaise and the Malaise + CO_2 traps. The complete Malaise trap captures are used, rather than only those on equivalent nights for these latter were too low for accurate analysis. These figures show that the addition of carbon dioxide to a Malaise trap greatly increases its catch and the numbers of nearly all species caught are increased. The increase for some species is greater than for others, *Aedes* species appearing to be more attracted to carbon dioxide than non *Aedes* species. Three *Aedes* species showed significantly higher proportion in Malaise + CO_2 traps; these were *A.vexans* in 1966 and *A.intrudens* and *A.punctor* in 1967. *A.punctor* showed no significant difference in 1966 and in fact the proportion was slightly higher in the Malaise traps, possibly because this species is relatively less abundant in August than in the spring. The greatly increased proportion of *A.vexans* in carbon dioxide traps

Table 15 Numbers of mosquitoes caught in Malaise and Malaise+CO_2 traps on equivalent nights at George Lake in July, August 1966 and May and June 1967.

Date	MI CO_2	MII	Date	MII CO_2	MI
1966					
27/28 July	79	4	28/29 July	134	2
2/3 Aug.	253	0	3/4 Aug.	24	4
4/5 Aug.	152	1	9/10 Aug.	48	8
10/11 Aug.	30	1	17/18 Aug.	27	1
18/19 Aug.	39	2	23/24 Aug.	27	0
24/25 Aug.	36	2	31/1 Sept.	4	1
Total	589	10	Total	264	16
Mw	48.2	1.3		28.5	1.8
Grand Total M+CO_2 853 Mw* 37.0					
Malaise 26 Mw 1.6					
1967					
16/17 May	13	3	17/18 May	14	0
24/25 May	1	1	23/24 May	17	0
30/31 May	2	0	31/1 June	457	5
7/8 June	452	7	8/9 June	1103	2
13/14 June	165	14	14/15 June	1590	5
21/22 June	240	4	22/23 June	536	6
29/30 June	207	13	28/29 June	1923	9
Total	1080	42	Total	5640	27
Mw	42.9	3.9		300.1	2.6
Grand Total M+CO_2 6702 Malaise 69					
Mw 114.1 3.0					

* Mw = Williams mean = antilog $\left(\frac{\Sigma \log (x+1)}{N}\right) -1$

x = Number per sample

N = Number of samples

Table 16 Proportion of female mosquito species in Malaise and Malaise + CO_2 traps at George Lake.

Species	1966 (August) Malaise	1966 (August) Mal.+CO_2	1967 (May-June) Malaise	1967 (May-June) Mal.+CO_2*
Anopheles earlei	1.1 (1)	0.1 (1)	0.8 (4)	0.3 (22)
Culiseta alaskaensis			2.2 (10)	1.7 (115)
C. inornata	25.8 (24)	0.8 (8)	1.2 (6)	0.1 (7)
Other Culiseta	7.5 (7)	0.1 (1)	2.8 (13)	0.3 (21)
Culex territans		0.1 (1)	6.5 (39)	0.02 (2)
Mansonia perturbans		1.7 (1)		
Total non Aedes	34.4 (32)	2.8 (23)†	13.5 (63)	2.4 (160)†
Aedes cataphylla			1.8 (8)	0.9 (60)
A. cinereus		1.7 (11)		0.02 (3)
A. communis		0.5 (3)	4.4 (21)	3.0 (200)
A. excrucians	25.8 (24)	16.2 (102)	14.8 (69)	15.7 (1055)
A. fitchii	5.4 (5)	4.4 (27)	6.9 (22)	5.6 (375)
A. implicatus		0.1 (1)	19.8 (93)	21.3 (1430)
A. intrudens			6.3 (29)	16.4 (1120)**
A. punctor	6.5 (7)	5.7 (36)	14.8 (69)	23.0 (1540)**
A. riparius	3.2 (3)	3.5 (22)	13.2 (62)	6.3 (420)
A. vexans	23.7 (22)	61.4 (386)**		

Table 16 continued.

Species	1966 (August) Malaise	Mal.+CO_2	1967 (May-June) Malaise	Mal.+CO_2*
Other *Aedes*	1.1 (1)	3.6 (23)	4.6 (22)	5.4 (360)
Total *Aedes*	65.6 (61)	97.1 (611)	86.5 (405)	97.6 (6560)
Total	93	633	468	6720
No. species	9	15	16	25
α	3 ± .6	4 ± .5	3 ± .4	3 ± .3
	X^2_7 = 184.484 P =<.001		X^2_7 = 235.787 P =<.001	

* Estimated total

** above expected in CO_2 trap

† below expected in CO_2 trap

Fig. in brackets = no. caught

Table 17 Comparison of mosquito captures per night in Malaise, Malaise + CO_2 and light traps at George Lake, July and August 1966 and May and June 1967.

	Malaise	Malaise CO_2	Light
1966			
No. caught	26	589	69
No. of trap nights	12	12	26
Mw*/trap night	1.6	37.0	1.7
Range	0-8	4-253	0-14
1967			
No. caught	69	6720	130
No. of trap nights	14	14	30
Mw/trap night	3.0	114.1	1.4
Range	0-14	1-1923	0-59

* Mw = Williams mean

is interesting as Huffacker and Bach (l.c.) took a lower proportion of this species in light traps with carbon dioxide than in light alone, but Carestia and Savage (l.c.) and Newhouse et al. (l.c.) took slightly higher proportions of A.vexans in light traps with carbon dioxide than with light alone. Both Carestia and Savage and Newhouse et al. found the proportions of Culex species were greatly increased when carbon dioxide was added to light traps. This did not occur at George Lake as the only common Culex was C.territans which feeds mainly on amphibians.

Table 17 shows the Williams mean catch per trap night in Malaise, Malaise + CO_2 and light traps. To obtain some idea on how carbon dioxide attracts mosquitoes I watched both traps on several evenings in May and June in 1967. The traps had to be observed through binoculars from at least twenty yards distance; otherwise the mosquitoes left the trap for the observer. About half an hour after the traps were started, a swarm of mosquitoes formed over the catching head of Malaise I + CO_2, which was on low ground. At Malaise II + CO_2, which was on the top of a low ridge, no swarm formed but large numbers of mosquitoes settled on the baffles of the trap, I saw very few settling on these in Malaise I + CO_2. Many of the settled mosquitoes crawled or flew upwards and were caught.

In both traps many mosquitoes remain settled very close to the carbon dioxide outlet for periods of up to fifteen minutes.

The formation of a swarm over the carbon dioxide outlet and the very large numbers caught show that carbon dioxide probably exerts a

Table 18 Comparison of the contents of the ventral diverticulum of mosquitoes caught in the trap types at George Lake in 1966.

Trap Type	Contents of Ventral Diverticulum 0	1	2	Mean	Total Examined
Malaise	64	60	6	0.6	130
Mal + CO_2	78	38	4	0.4	120
Light	51	46	3	0.5	100
Vis. Attr.	21	26	3	0.6	50
Rotary	25	39	4	0.7	68
Rat bait	45	49	3	0.6	97
Chick. bait	13	6	2	0.5	21
Coll. in trailer	22	37	5	0.7	64
Total catch	319	301	30	0.6	650

0 = empty

1 = partially full

2 = full

considerable orienting stimulus to adult female mosquitoes; but it is easily overridden by the approach of a host animal such as man.

3.5. Physiological state

3.5.1. The contents of the ventral diverticulum

Trembley (1952) and Hocking (1954b) have shown that sugar solutions and nectar normally pass into the ventral oesophageal diverticulum and not into the stomach. Hocking (l.c.) has shown the importance of nectar as an energy source for mosquitoes. Thus, the contents of the ventral diverticulum are a partial measure of the energy resources available to the mosquito. The amounts of liquid in the ventral diverticulum in female mosquitoes caught in different trap types are shown in Table 18. In most mosquitoes the ventral diverticula were either empty or only partially filled; in only 30 out of 650 mosquitoes were they full.

There were no significant differences between trap types.

3.5.2. Ovarian development and stage in gonotrophic cycle

Tables 19 and 20 show the stages of Sella and Tables 21 and 22 show the stages of Christophers. Table 23 shows the occurrence of gravid females in the traps. In 1966 light traps caught a significantly higher proportion of the higher stages than the other traps but this was not so in 1967. A striking difference between the two years was the large number of resting mosquitoes which had ovaries in stages III-V of Christophers in 1967, which has been discussed in section 2.4.

Three gravid females were taken in animal bait traps and seven in carbon dioxide traps, but it is unlikely they were attracted to the bait.

Table 19 Comparison of the stages of Sella of mosquitoes caught in the different trap types at George Lake over the periods 1st June to 1st September 1966 and 16th May to 30th June 1967.

1966

Trap type	Stage of Sella 1	2	3	4	5	6	7	Mean	Total examined
Malaise	152	3	1				28	1.9	184
Mal. CO_2*	178	1		2	1		6	1.3	188
Light	95	1	1	1	1	3	75	3.7**	177
Vis. attr.	59	1	2		1	1	2	1.3	65
Rotary	77	1	2	2		1	4	1.5	87
Rat bait	124	6						1.0	130
Chick. bait	27	3						1.1	30
Coll. in trailer	76	2			1			1.1	79

* operated from 27th July to 1st September only

** $\chi^2_4 = 186.220 = P < .001$

1967

Trap type	Stage of Sella 1	2	3	4	5	6	7	Mean	Total examined
Tot. malaise	129		1			2	2	1.2	134
Tot. Mal CO_2	319	1	7	1				1.1	328
Tot. Light	108	2						1.0	110
Vis. attr.	48	1		1				1.1	50
Rotary	70		1					1.0	71
Rat bait	85	1	3					1.1	89
Trailer	43	7	10	10	5	4	6	2.6	85

Table 20 Comparison of the stages of Sella of Aedes species in the different trap types at George Lake 1st June to 1st September 1966 and 16th May to 30th June 1967.

1966

Trap type	Stage of Sella 1	2	3	4	5	6	7	Mean	Tot. examined
Malaise	146	1	1				5	1.2	153
Mal. CO_2*	167	1		2			3	1.1	173
Light	63						6	1.5	69
Vis. attr.	46		2		1		1	1.3	50
Rotary	65		2	2	1	1	2	1.4	73
Rat bait	120	6						1.0	126
Chick. bait	27	3						1.1	30
Trailer	74	2						1.1	76

* only operated 27th July to 1st September

No significant difference

1967

Trap type	Stage of Sella 1	2	3	4	5	6	7	Mean	Tot. examined
Tot. Malaise	122		1			1	1	1.0	125
Mal. CO_2	276	1	6					1.0	283
Tot. Light	95	1						1.0	96
Vis. attr.	43			1				1.1	44
Rotary	69		1					1.0	70
Rat bait	84	1	3					1.1	88
Trailer	28	6	8	4	1		1	1.9	48

Table 21 Comparison of the stage of Christophers of mosquitoes in different trap types at George Lake from 1st June to 1st September 1966 and 15th May to 30th June 1967.

1966

Trap type	Stage of Christophers I	II	III	IV	V	Mean	Tot. examined
Malaise	57	80	8	5	23	2.2	173
Mal. CO_2*	77	94	2	1	6	1.7	180
Light	30	51	7	6	71	3.2**	165
Vis. attr.	27	28	3	1	2	1.7	61
Rotary	29	45	3	2	4	1.9	83
Rat bait	43	78				1.6	121
Chick. bait	5	21				1.8	26
Trailer	32	41	4			1.6	77

* only operated 27th July to 1st September

** significant at 1% level $X^2_4 = 198.005$ $P = <.001$

1967

Trap type	Stage of Christophers I	II	III	IV	V	Mean	Tot. examined
Tot. Malaise	32	97	1	2	2	1.8	134
Mal. CO_2	100	216	9		2	1.7	327
Light	19	87	1			1.8	107
Vis. attr.	11	37	2			1.8	50
Rotary	13	54	3			1.8	70
Rat bait	14	71	2			1.9	87
Trailer	7	50	16	6	6	2.4	85

Table 22 Comparison of the stage of Christophers of Aedes species in different trap types at George Lake, 1st June to 1st September 1966 and 16th May to 30th June 1967.

1966

Trap type	Stage of Christophers I	II	III	IV	V	Mean	Tot. examined
Malaise	55	77	8	1	5	1.8	146
Mal. CO_2*	75	92	2		4	1.7	173
Light	12	45	4		6	2.2**	67
Vis. attr.	21	22	2	1	1	1.7	47
Rotary	23	39	3	2	1	1.8	68
Rat bait	43	72				1.6	115
Chick. bait	5	21				1.8	26
Trailer	31	40	4			1.6	75

* Only operated 27th July to 1st September

** significant at 1% level. $X^2_3 = 19.27$ $P = <.001$

1967

Trap type	Stage of Christophers I	II	III	IV	V	Mean	Tot. examined
Tot. Malaise	32	89	1	1	1	1.8	124
Mal. CO_2	100	171	7		2	1.7	280
Tot. Light	17	76	1			1.8	94
Vis. attr.	10	32	2			1.8	44
Rotary	13	53	3			1.8	69
Rat bait	14	70	2			2.0	86
Trailer	7	33	10	1	1	2.2	52

Table 23 Occurrence of gravid female mosquitoes in the different traps at George Lake in 1965, 1966 and 1967.

Species	Mal I	Mal II	Mal I+ CO_2	Lt. I	Lt. II	Vis. Attr.	Rot.	Anim. bait	Trailer	Total
Anopheles earlei			1	2			1		4	8
Culiseta alaskaensis	2									2
C. inornata	31			93	6			2		132
Culex territans	1	1				1	1		1	5
Aedes communis	1									1
A. excrucians	1		1		1	1	2			6
A. implicatus	1	1							1	3
A. intrudens			1							1
A. pionips				1		1				2
A. vexans	4		1	2	3		1			11
Unidentified								1		1
Totals	41	2	4	98	10	3	5	3	6	172

Corbet (1961a) found that in Mansonia fuscopennata (Theobald), in Uganda, light traps sampled only those specimens engaged in "non-specific activity" i.e., those not engaged in swarming, biting, or ovipositing. Standfast (1965) confirmed this for Culex annulirostris Skuse but he believed this indicated activity in the intermediate stages of the gonotrophic cycle, that is females in stages III and IV of Christophers or three to six of Sella. Corbet (1961a), on the other hand, found 90% of M. fuscopennata in light traps were in stages I and II of Christophers and none were gravid. George Lake results do not support this since a number of gravid females and individuals in intermediate stages of the gonotrophic cycle were taken in light traps. Most of the gravid females in light traps were Culiseta inornata, a species known to have abberrant mating behavior (Kliewer 1966) and which may be abberrant in other aspects as well, but several gravid Aedes females were also taken at light. Both Corbet and Standfast based their conclusions on the fact that peak light trap captures did not coincide with peaks of biting, swarming or oviposition activity. Captures were not recorded at hourly intervals at George Lake, but mosquitoes were often found biting round light traps in the evenings and in the mornings of nights when none were caught. Corbet and Standfast worked on tropical mosquitoes, which may explain some of the differences.

3.5.3. Physiological age of adult females as shown by the parity rate

In three years of study 1683 pairs of ovaries were examined for parity. The proportions of pars in the traps are shown in Tables 24-28. Except in August 1966, light traps caught a higher proportion of

Table 24 Parity rate of mosquitoes in trap types at George Lake 1st June to 1st September 1966.

Trap type	Parous	Nulliparous	P:N+P
Malaise	57	87	.40
Light	49	41	.49**
Vis. attr.	19	36	.34
Rotary	32	43	.42
Rat bait*	42	50	.46
Coll. in trailer	30	43	.41
Total	229	300	.43

* Operated 27th July to 1st September only

** significant at 5% level for those traps run for the whole period.

X^2_2 = 5.447 (Light vers. rest) P = <.05

Table 25 Comparison of parity rate of mosquitoes in trap types operated in August 1965 and August 1966 at George Lake.

Trap type	1965 Par	1965 Null	1965 P:N+P	1966 Par	1966 Null	1966 P:N+P
Malaise	12	10	.54	19	11	.64
Mal. CO_2	Not done			82	30	.73
Light	30	13	.70	15	10	.60*
Vis. attr.	5	7	.42	7	2	.78
Rotary	1	3	.25	11	1	.92
Animal bait	24	15	.62	40	11	.78
Trailer	Not done			8	3	.73
Total	72	48	.60	182	68	.73
	X^2_2 = 4.523 P =<.05 (Lt. vers. rest)			not significant		

* all 13 *Aedes* sp. caught were parous.

Table 26 Comparison of the parity rate of mosquitoes taken in various trap types at George Lake in June 1966 and 1967.

Trap type	June 1966			May, June 1967		
	P	N	P:P+N	P	N	P:P+N
Malaise	17	43	.28	17	115	.13
Mal. CO_2	-	-	-	51	278	.16
Light	13	18	.42	37	112	.25
Vis. attr.	8	24	.25	3	44	.06
Rotary	8	27	.22	14	57	.20
Rat bait	17	31	.35	9	78	.10
Total	63	143	.31	131	684	.11
no significant difference between traps at 0.05 level.				$X^2_5 = 15.75$ $P =< .01$		

Table 27 Comparison of the parity rate in Aedes species at George Lake in trap types operated for the whole period, 1st June to 1st September 1966, and May, June 1967

Trap type	Par	Null	P:N+P
1966			
Malaise	52	85	.38
Light	35	25	.58
Vis. attr.	14	28	.33
Rotary	25	27	.48
Rat bait I	38	48	.44
Coll. in trail.	29	42	.41
Total	193	255	.42

$X^2_2 = 7.967$ P =<.01 (light vers. rest)

May, June 1967

Trap type	Par	Null	P:N+P
1967			
Malaise	17	109	.15
Malaise CO_2	32	243	.12
Light	26	68	.28
Vis. attr.	3	38	.07
Rotary	14	56	.20
Rat bait I	8	77	.09
Total	100	591	.14

$X^2_5 = 20.14$ P =<.01

Table 28 Comparison of the parity rate of selected mosquito species in trap types at George Lake (Results for 1965, 1966 and 1967 combined).

Trap	Species *Anopheles earlei*	*Culiseta inornata*	*Aedes excrucians*	*A. punctor*	*A. vexans*
Malaise	0.50 (4)	0.60 (15)	0.30 (79)	0.16 (37)	0.66 (21)
Light	0.54 (28)	0.63 (19)	0.56 (55)	0.35 (31)	0.70 (20)
Vis. attr.	0.42 (12)	0.14 (7)	0.25 (20)	0.25 (24)	0.50 (4)
Rotary	0.67 (6)	0.00 (3)	0.33 (9)	0.27 (45)	0.17 (6)
Bait	-	0.5 (4)	0.38 (57)	0.14 (49)	0.36 (14)

Figure in brackets = no. examined

pars than other traps. In August 1966 the greater part of the light trap catch was Culiseta inornata and Anopheles earlei, most of which were probably about to overwinter and these species appear to overwinter as nullipars. All the Aedes taken in light traps in August 1966 were parous. The statistical significance of the higher proportion of pars in light traps is doubtful. In 1965 and 1966 the proportion of pars in light traps was significantly higher at the 5% level when tested against the rest combined but not significant when the traps were tested individually. In the spring of 1967, however, the proportion of pars in light traps was significantly higher at the 1% level when the traps were tested individually. In all cases the parity rate in light traps was higher for Aedes species than for the total catch.

Table 31 shows the parity rate in five species taken in different trap types. With the exception of Anopheles earlei the parity rate in light traps was higher than in other traps.

It is clear that light traps have a slightly higher attraction for older female mosquitoes than the other trap types tested.

3.6. Environmental relationships - Malaise and light traps

Factors controlling the activity of adult mosquitoes have been reviewed by Bates (1949), Clement (1963) and Dogiel (1964). The design of the study at George Lake permitted only three factors to be evaluated: temperature, humidity, and the lunar phase.

3.6.1. Temperature

The minimum nightly temperature was chosen as an index of the coldness of the night. Figure 23 shows the relationship between nightly

catches (logx + 1) of mosquitoes and minimum temperature in light and Malaise traps, and figure 24 the Williams mean catch per 2 C range in minimum temperature in light traps in 1966.

There was a significant correlation between minimum temperature and catch in both Malaise and light traps, which shows that mosquitoes are more active on warm than cold nights.

3.6.2. Humidity

Figure 23 shows the relationship between the mean saturation deficit per night taken at 2000 hours, 2400 hours, and 0600 hours, and the catch in Malaise and light traps in 1966. There was no correlation over the range of saturation deficits recorded, but the highest recorded deficit was only 11.3 mm Hg.

3.6.3. Lunar phase

It has long been known that moonlight lowers the catches of insects in light traps (Williams *et al*. 1956; Taylor and Carter 1961; Horsfall 1943; Pratt 1948; and Provost 1959). Table 29 shows the captures of mosquitoes in light and Malaise traps at new, quarter, and full moon, at George Lake in 1966 and in light trap captures at Edmonton in 1965. Contrary to expectation the average number per night at George Lake was greater at full than at new moon. However, the mean minimum temperature was lower at new moon and the cloud cover, as indicated by the cloud cover index* was greater on nights with full moon, which probably accounts for the higher numbers of mosquitoes caught in light

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* See Table 29, p. 95.

Table 29 Effects of the phase of the moon on light and Malaise trap captures of mosquitoes at George Lake, 1st June to 1st September 1966 and on a light trap at Edmonton 9th July - 31 August 1965.

GEORGE LAKE

	Light Traps		
	Full ± 3 days	Quarter ± 3 days	New ± 3 days
Total catch	50	94	27
No. observ.	8	16	8
Williams mean	5.8	7.7	2.1*
Mean Min. temp.	9.4C	8.4C	6.3C
Index. Cloud cover**	7.2	5.0	3.6
	Malaise Traps		
Total catch	31	82	43
No. observ.	6	11	7
Williams Mean	4.4	5.3	4.4
Mean Min. temp.	8.0C	7.8C	6.6C

EDMONTON

		Light Traps	July and August 1965
Total catch	822	1206	875
No. observ.	12	14	9
Williams mean	30.2	38.7	49.3

* significantly lower at 5% level

** Cloud cover index = average cloud cover in 10ths per hour per night. (Data from Dept. of Transport, Meteorology Branch Nisku airport.)

traps at full moon. Light trap captures in Edmonton in 1965 were as expected with the highest mean capture at new moon and the lowest at full moon.

No significant differences were found between mean captures in Malaise traps and the lunar phase, which does not support the findings of Biddlingmayer (1964, 1967) that more mosquitoes are active at full moon than at new moon.

3.6.4. Discussion

Taylor (1963) has shown that temperature affects the flight activity of insects by inhibiting at below a threshold value rather than by a gradual correlation and that such a correlation is only obtainable when a multi-species population is studied, as occurred at George Lake. This may account for the fact that Platt *et al*. (1958) found no correlation between temperature and flight activity in *Aedes vexans*. Hocking *et al*. (1950) found there was no variation in the attack pattern of adult female mosquitoes at Churchill, Manitoba, between 10.0 C and 27.8 C, but it fell off above and below these limits. Gracheva and Shevkunova (1959) found *Aedes punctor* and *A.communis* in Russia were active down to 2.5 C, indicating that northern mosquitoes have very low temperature thresholds for flight activity. This was supported at George Lake for mosquitoes were taken on nights on which the temperature fell to 1.1 C. Species found flying on nights with temperatures below 2.0 C were *Aedes pullatus*, *A.trichurus*, *A.excrucians*, and *A.riparius*, none of which are truly northern mosquitoes.

Verhiejen (1960) has shown that the effect of a light as an

attractant for insects is dependent on the degree of its contrast with its surroundings, which explains the lower catches in light traps at full moon. Light intensity is believed by many authors (Snow and Pickard 1957; Platt _et al_. 1957; Matheson 1944 and others) to be a major factor in controlling mosquito activity. Biddlingmayer (1964) believed more mosquitoes were active at full moon than new moon and attributed this to favourable light intensities lasting longer at full moon. George Lake results did not confirm this and Clement (1963) has shown that there is a circadian rhythm of activity in mosquitoes and Corbet (1966) has shown that this is detectable in high arctic species where daylight lasts for twenty-four hours.

There is some controversy over the role of humidity in determining mosquito activity. Happold (1963, 1965b) found a significant correlation between saturation deficit and mosquito flight activity but none between relative humidity and flight activity. Platt _et al_. (1958) found a positive correlation between relative humidity and light trap captures of _Aedes vexans_, but Monchadski (1950, 1956) found humidity had no effect on the biting rate of _Aedes_ species in Russia. Some of this controversy may be due to the fact that different activities were studied and humidity may well affect activity in different ways depending on the type of activity. This does not seem to have been clearly recognized in the past. The humidity range recorded at George Lake was too small for any conclusions to be made.

In conclusion, mosquito activity is probably largely dependent on circadian rhythms but these are modified by environmental factors such

as temperature, light intensity, and humidity (Clement 1963). Different types of behaviour are probably affected in different ways by the environment and this must be taken into consideration in ecological work which involves traps such as bait and light traps.

3.7. Damage to mosquitoes by different collection methods

I noticed that the condition of specimens caught in different traps varied considerably. I investigated this using the damage categories described in section 1.2.4.2. for ageing by external appearance. The results are shown in Table 30. The specimens taken in Malaise traps both with and without carbon dioxide are in much better condition than those taken in other traps, probably because the insects were dead before falling into the collecting bottle and there were no moving parts in the traps. These traps also involved a minimum of handling both during and after capture. The rotary trap damaged specimens more than any other and the mean shown is possibly too low as the catch of this trap included a high proportion of unidentified specimens which were not assigned to any damage category.

3.8. General discussion

Southwood (1966) has reviewed methods of sampling insects, including mosquito populations. Though a great deal of ingenuity has been expended on the design of methods for sampling adult mosquito populations and on the refinement of these methods, they are mainly aimed at the largest possible catch. A few methods have been designed for special purposes such as window traps (Muirhead - Thompson 1951) which are designed to catch mosquitoes entering or leaving buildings,

Table 30 Comparison of the damage done to mosquito specimens by different trap types.

Trap type	Damage Category* 0	1	2	3	4	5	Mean	Total Examined
Malaise	40	38	73	12	16	3	1.6	182
Mal. CO_2	44	48	65	22	5	2	1.5	186
Light	8	16	31	23	43	31	3.1	152
Vis. attr.	8	6	23	6	19	10	2.7	72
Rotary	0	4	13	16	36	25	3.9	84
Rat bait	5	7	40	23	54	21	3.2	150
Chick. bait	2	4	11	9	7	8	2.9	41
Coll. in tr.	7	10	45	35	13	16	2.9	126

* categories same as those in section 1.3.4.2.

a trap to catch mosquitoes emerging from cesspits (Salternik 1960) and several traps designed to catch resting mosquitoes (Russell and Santiago 1934; Smith 1942; Snow 1949; and Muirhead - Thompson 1958). These methods are usually biased towards a few species, many resting-site methods have been designed to catch Anopheline vectors of malaria. Methods designed for general survey work should catch as wide a spectrum of species as possible and should not be selective for any species or physiological state.

A large number of factors affect the efficiency of sampling methods. One of these is geographical location. The pit shelter (Muirhead - Thompson 1958), was designed and worked well in Rhodesia and in Java (D.A. Muir, pers. comm.), two areas very different in climate and with very different mosquito species but failed when tried in Sarawak, an area similar in climate and with many mosquito species in common with Java.

The methods I tested were all designed to be of use in general survey work. The findings may apply only to central Alberta but should also apply to much of the southern part of the boreal forest in which similar conditions and species occur. The mosquito fauna of this area is peculiar for the great preponderance both in the numbers and in the number of species of Aedes and the relative unimportance of all other genera except Culiseta. At George Lake five genera were found but Aedes comprised 72% of the species and 85% of the individuals. This can be compared to Kentucky, where eight genera were found and Aedes comprised 31% of the species and 52% of the individuals (Breeland

and Pickard 1965). It is thus improbable that findings in one area will apply *in toto* to the other.

The importance of the physiological state of the mosquitoes has been ignored in most studies on sampling adult mosquito populations. Bursell (1961) showed that the physiological state of tsetse flies (*Glossina swynnertoni* Austen) varies according to the sampling method used and this greatly affected interpretation of the results. Differences in the physiological age of mosquitoes taken by different sampling methods could affect the results in disease transmission studies, as mosquitoes only become infected with disease-causing microrganisms after they have fed on an infected host. Thus a trap which takes a higher proportion of physiologically older females than occur in the population will give an exaggerated infection rate and if the method is selective for a few species may cause the vectorial importance of some species to be overrated. Though such a method may be useful where infected females are rare or a pool of mosquitoes is used and an exact infection rate is not required.

The low activity of the adult females in stages III and IV of Christophers is important and must be taken into account in population studies using sampling methods which catch active mosquitoes, as this means that a significant proportion of the population is inactive and so unavailable for sampling. Most studies, including this one, which show population peaks of mosquitoes are actually showing peaks of activity rather than actual population peaks and though the activity and population peaks are probably similar, this is by no means certain.

Methods of capturing resting adult female mosquitoes are inaccurate, biased towards a few species and almost impossible to correlate with methods of taking active mosquitoes. If the length of the gonotrophic cycle at different temperatures and the average number of gonotrophic cycles passed through by the females in a population were known, an estimate of the proportion in the stages III and IV of Christophers could be obtained. Polovodova's method enables the number of gonotrophic cycles passed through by a female mosquito to be accurately determined and work on this in North America has been started both on Culex tarsalis (Nelson 1964, Burdick and Kardos 1963) and on univoltine Aedes species (Carpenter and Nielson 1965), but almost nothing appears to be known of the length of the gonotrophic cycle in most North American species of mosquito. This is a fruitful field for future research. The use of Polovodova's method in determining the life history, vectorial importance and population dynamics of Anopheles maculipennis Meigen is shown by Detinova (1962).

The contents of the ventral diverticulum provide a partial measure of the energy reserves available to the mosquito. Theoretically it should be possible to distinguish the proportion of mosquitoes which have recently migrated into an area; these should have empty or nearly empty ventral diverticula, having used up most of their energy resources on the flight and the resident population should have full or nearly full diverticula. However, it would be necessary to conduct a thorough investigation of the nectar resources available and of the plants frequented by mosquitoes before the contents of the ventral

diverticulum could be used to distinguish migrants from resident mosquitoes. At George Lake the majority of mosquitoes had empty or only partially filled ventral diverticula in 1966. Since flowers were abundant during the whole of the investigation, it is possible that many of the mosquitoes caught had migrated in from outside the field site; this is supported by the very few larvae found near the study area and the few males caught. Males are believed to be more sedentary than females, seldom moving more than a few miles from breeding sites, while adult female *Aedes* in temperate regions may undertake long distance migrations (Clement 1963).

Since male mosquitoes do not take blood meals, relatively little attention has been paid to them in the past, as is shown by the few references to males in Bates (1949) and Clement (1963). I paid little attention to male mosquitoes in this study. In the last few years the development of sterile male methods of insect control has resulted in considerable interest in male mosquitoes. Males probably give a better idea of the population breeding in the vicinity of the study because they are more sedentary than the females and the adult males of many species provide more reliable characters for specific determination than do the adult females. It is unlikely that any one method will be equally effective for sampling both adult females and adult males because their biologies differ considerably. The swarming habits of the males of many species of mosquito will make the siting of traps even more critical for males than females and this, coupled with the fact that females appear to be longer lived than males and as they

only mate once, it is unlikely that any one sampling method will give a true sex ratio. The important sex ratio, the number of males to unmated females, can probably be best estimated from rearing experiments.

3.8.1. Methods believed to take a random sample of the active population

Malaise traps exert no recognizable attraction to mosquitoes and so I believe they take a random sample of the active mosquitoes and that this is unbiased both towards species and towards physiological state. There is one possible area of bias, that is, against blood meal seeking mosquitoes. If the generally accepted theory of host finding in mosquitoes, which is, that the biting cycle represents the frequency with which a population in random flight comes within the range of attraction of a host (Mattingly 1949), is correct then there is no bias. However, Corbet (1961a) has shown that there may be a definite urge to bite and it is possible that some mosquitoes with this urge may rest on the vegetation until activated by the presence of a possible host as do tsetse flies (Glossina species) (Glascow 1963). If this is so then not many hungry mosquitoes will be caught in Malaise traps which would introduce an element of physiological bias.

At George Lake the proportion of the rarer species in Malaise traps was less than in traps which used an attractive element, which indicates that these traps are unlikely to catch large samples of these species, though they took a larger number of species than any other trap type probably because of the longer operating time. The four species not taken in Malaise traps were all rare, no more than two specimens of each being taken by all methods in 1966. No species

were taken by Malaise traps alone. Breeland and Pickard (1965) found that Malaise traps caught a higher proportion of rare species and several species they recorded were only taken in Malaise traps.

The Malaise trap has certain advantages over other traps; it has no moving parts; it can work with a minimum of servicing, and needs to be emptied only once or twice a week, which allows it to be operated in remote places; it operates twenty-four hours a day and the catch is preserved in good condition. A few disadvantages are important; if left for any length of time spiders spin webs across the entrances; it is very vulnerable to vandalism; low efficiency and large size make it necessary to operate this trap for a prolonged period in a single site and the position of the trap is more critical than for other trap types; many mosquitoes which enter the base of the trap get attracted out before they are caught, so that the number seen round the traps is no indication of the catch; and it is very difficult to obtain a meaningful estimate of the volume of air filtered and so obtain an absolute density figure. These disadvantages may preclude the use of Malaise traps for some studies.

Smith _et al_. (1965) found Malaise traps alone were capable of predicting outbreaks of biting flies in Kentucky. The advantages listed above make this trap superior to most other presumably unbiased methods of collection where absolute density figures are not required.

Suction traps (Southwood 1966) require a motor or permanent electric supply and require regular servicing. The position of these traps is critical as in Malaise traps. The volume of air filtered

Much the same is true of the visual attraction trap, though this trap probably does take a random sample of active mosquitoes.

If a random sample of active mosquitoes over a prolonged period is required and absolute density figures are not necessary, Malaise traps can obtain this with less trouble than any type of mechanical trap and are just as capable of detecting variations in population level. Where a large sample is required or only a limited time is available some other method such as visual attraction or car trap will possibly be better.

3.8.2. Methods known to take biased samples of the population

Methods which use light, a bait or which capture mosquitoes in resting places are considered here.

A large number of designs of light traps for insects have been described (Southwood 1966), but relatively few are suitable for mosquitoes. Many small insects including mosquitoes are repelled by strong light (Verhiejen 1960; Barr *et al*. 1963) and so traps designed to catch these usually include a suction fan, like the New Jersey trap. Loomis (1959) considered that the air flow through a New Jersey trap must be standardized if two traps are being compared. At George Lake in 1966 the number of mosquitoes per 10,000 cu. ft. of air filtered was 0.73 in light I and 0.25 in light II which are in the same ratio as the catches per 100 trap hours are (2.9). This shows that the difference between the catches in the two traps was not due to difference in air flow through them.

Barr *et al*. (1963), Bargren and Nibley (1956), Headlee (1937) and

Johnson (1938) have shown that both intensity and color of the light as well as the species of mosquito are important. The distance from which a light trap attracts a mosquito is not known, but Barr _et al_. (1963) believe it is very small. Since the trapping effect of light is caused by interference with the normal photic orientation of the insect (Verheijen _l.c._), the attractiveness of a light depends on the degree of contrast to the surroundings, more mosquitoes should be caught on dark than light nights (see section 3.6.4.) and this is normally the case. However, Barr _et al_. found that _Culex pipiens quinquefasciatus_ (Say) showed signs of being more attracted to light on light rather than on dark nights; so there are probably exceptions.

The species composition of light trap captures is usually considerably different from that in the natural population. This has been shown by Southwood (1960) for Heteroptera and it has also been found in mosquitoes. The attraction to light may vary within a single species over its geographical range and under different environmental conditions. _Anopheles earlei_ was one of the species in which a high proportion of the catch was taken in light traps at George Lake, but McLintock _et al_. (1966) found a much lower proportion of this species was taken by light traps than in collections by other methods in Saskatchewan. Bargren and Nibley (_l.c._) and Reed (1954) found _Culex tarsalis_ and _C.p.quinquefasciatus_ equally or more abundant in unlighted as in lighted New Jersey light traps. Bargren and Nibley believed this means that some _Culex_ species may find New Jersey light traps desirable daytime resting places, but Barr _et al_. (1963) consider

this unlikely.

Light traps can only provide data on relative changes in mosquito populations and are probably of little use in life-table studies or in studies in which the true species composition of the mosquito fauna is required. In spite of many drawbacks, light traps are useful survey tools for mosquitoes and, if the attraction for older (parous) mosquitoes is found to be widespread, will prove especially useful in some disease transmission studies. Light traps are easily standardized and if run in the same place over a long period give an indication of population changes. Clark and Wray (1967) used light traps in studies which enabled accurate prediction of Aedes vexans invasions of Illinois cities. Few modern workers would go as far as Mulhern (1953), who stated that since light traps were mechanized they gave better results than methods involving collection by hand, such as human biting rate collections, since these have a human element in them.

Light traps are particularly efficient for male mosquitoes (Belton and Galloway 1965; Southwood 1966) and they are probably the most efficient method of sampling males. Light traps were not very effective at George Lake because it is near the northern limit at which light traps are useful.

Animal bait traps are often used and collections of mosquitoes settling on man have frequently been used to obtain density figures for mosquitoes. Human baited traps are described by Klock and Biddlingmayer (1953) and Gater (1935), and traps baited with large animals by Magoon (1935), Shannon (1939), Bates (1944) and

Roberts (1965). Wharton et al. (1963) modified a Malayan trap (Gater l.c.) for use with monkeys as bait. In recent years interest has arisen in mosquitoes which attack birds, in connection with studies on arbor viruses, and several traps baited with chickens or other birds have been described (Rainey et al. 1962 and Fleming 1959). Lumsden (1958) and Worth and Jonkers (1962) have designed traps which use small vertebrates as bait. The Lumsden trap uses a fan and can give timed captures; portable versions of it are described by Snow et al. (1960) and Minter (1961).

The advantages of small mammal traps seem to be great. At George Lake captures in rat baited traps were very similar in composition to human bait captures, so white rats appear to have great value as bait in mosquito surveys. They are hardy, can survive outdoors if given shelter and can be left unattended for several days. As they give an approximation of the human biting rate they will give an idea of the nuisance value of the mosquito species present. Human bait captures while very useful can only be done for limited periods and are more expensive. Birds require more attention and large traps, and, while essential in some virus transmission studies, they may give a false impression of species composition, in studies, where nuisance to man is important.

The only animal-substitute bait tested was carbon dioxide. When added to a Malaise trap this greatly increased both the catch and the number of species per unit time, but it appears to be especially attractive to some species, destroying the random nature of Malaise trap

captures. For most purposes this is probably not too great a disadvantage and the increased catch will offset this, as the species attracted will probably be pest species.

The erratic behaviour of the dry ice trap of Bellamy and Reeves (1952) was possibly due to the small entrance area since the orienting stimulus of carbon dioxide appears to be weak. The main disadvantage of the addition of carbon dioxide from a cylinder to Malaise traps is that it is expensive and cannot be operated in remote places. However, dry ice is reasonably cheap and when in large enough blocks and suitably packed can last for several days while emitting large quantities of carbon dioxide. I believe that a useful mosquito trap for general survey purposes in places which cannot be visited every day would be a Malaise type trap modified to use dry ice as a bait. In central Alberta twenty-five pounds of dry ice lasts two to three days, which would make it possible to service this trap at biweekly intervals. Alone or combined with small mammal bait traps these traps could be operated in places several miles from a city, close to major mosquito breeding areas, and provide accurate data for forecasting the need for control measures in the city.

Ølkowski et al. (1967) found Malaise traps baited with dry ice caught significantly more Tabanids (Diptera; Tabanidae) than did unbaited traps in California. At George Lake Tabanids were too scarce and erratic in occurrance for any conclusions to be drawn. Anderson et al. (1967) found the same proportion of the population of *Symphoromyia* (Diptera; Leptidae) were taken in Malaise traps baited with

dry ice as were attracted to their natural hosts. They considered that these traps could give equivalent information on factors influencing attack rates as could direct observation and collection of the flies from the hosts, at a lower cost.

Collections in resting sites are useful for a few limited purposes, especially for obtaining blood fed females for host determination. (Division of Malaria Eradication, World Health Organization and Lister Institute of Preventive Medicine 1960; Corbet and Downe 1966) or for obtaining detailed information on the resting habits of mosquitoes for control with residual insecticides (Muirhead - Thompson 1951). These methods have proved very valuable in studies on anophelines but less successful for northern *Aedes*.

Results from central Alberta (this study and Happold 1965b) indicate that no local *Aedes* species exhibit any special tendency to enter buildings, but *Anopheles earlei*, *Culiseta inornata* and *Culex tarsalis* are known to hibernate in basements. Shemanchuk (1965) has shown that the principal hibernation sites of these species are in animal burrows. Further studies on the resting habits of Alberta mosquitoes are required.

3.8.3. Conclusions

The principal conclusions drawn from this study are that the position as well as the trap type greatly affects the size and composition of the catch. Malaise traps both with and without carbon dioxide are probably the most useful types of traps for general mosquito survey work as they can be operated away from sources of power and need

relatively little attention. Light traps will continue to be very useful in mosquito surveys, especially inside urban areas, as long as their limitations are clearly understood. Animal bait and resting-site captures are useful for specific purposes. Human bait captures are particularly useful for assessing mosquito nuisance and should always be used by urban mosquito control organizations in conjunction with other sampling methods but are of little value alone for forecasting the need for adult control measures in cities.

Although not tested in this study, car trap captures will probably be very useful in areas where vandalism or other factors prevent the use of Malaise or animal bait traps outside the city limits, but they should not be used instead of these.

APPENDIX

Results of Duncan's Multiple range test on the total numbers of mosquitoes caught per 100 hours in different traps at George Lake 1st June - 1st September 1966.

M.I M.II Lt.II R.Bait I V.Attr. Rot. Lt.I $MI+CO_2$ $MII+CO_2$

Traps underlined by the same line are not significantly different but differ significantly at 5% level from those not underlined by the same line, thus M.I does not differ significantly from V.Attr. but does differ from Rot.

MI = Malaise I

MII = Malaise II

$MI+CO_2$ = Malaise I + CO_2

$MII+CO_2$ = Malaise II + CO_2

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